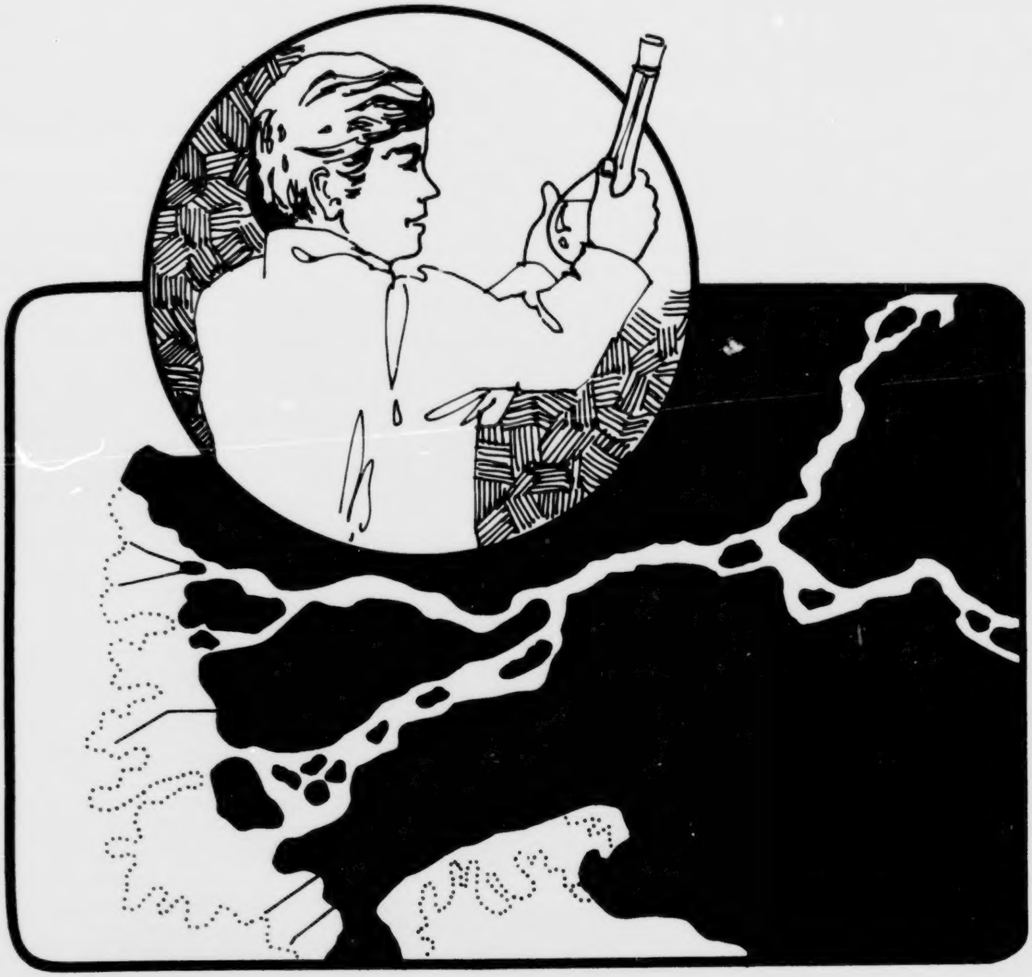
Fraser River Estuary Study
Water Quality

Aquatic Biota and Sediments



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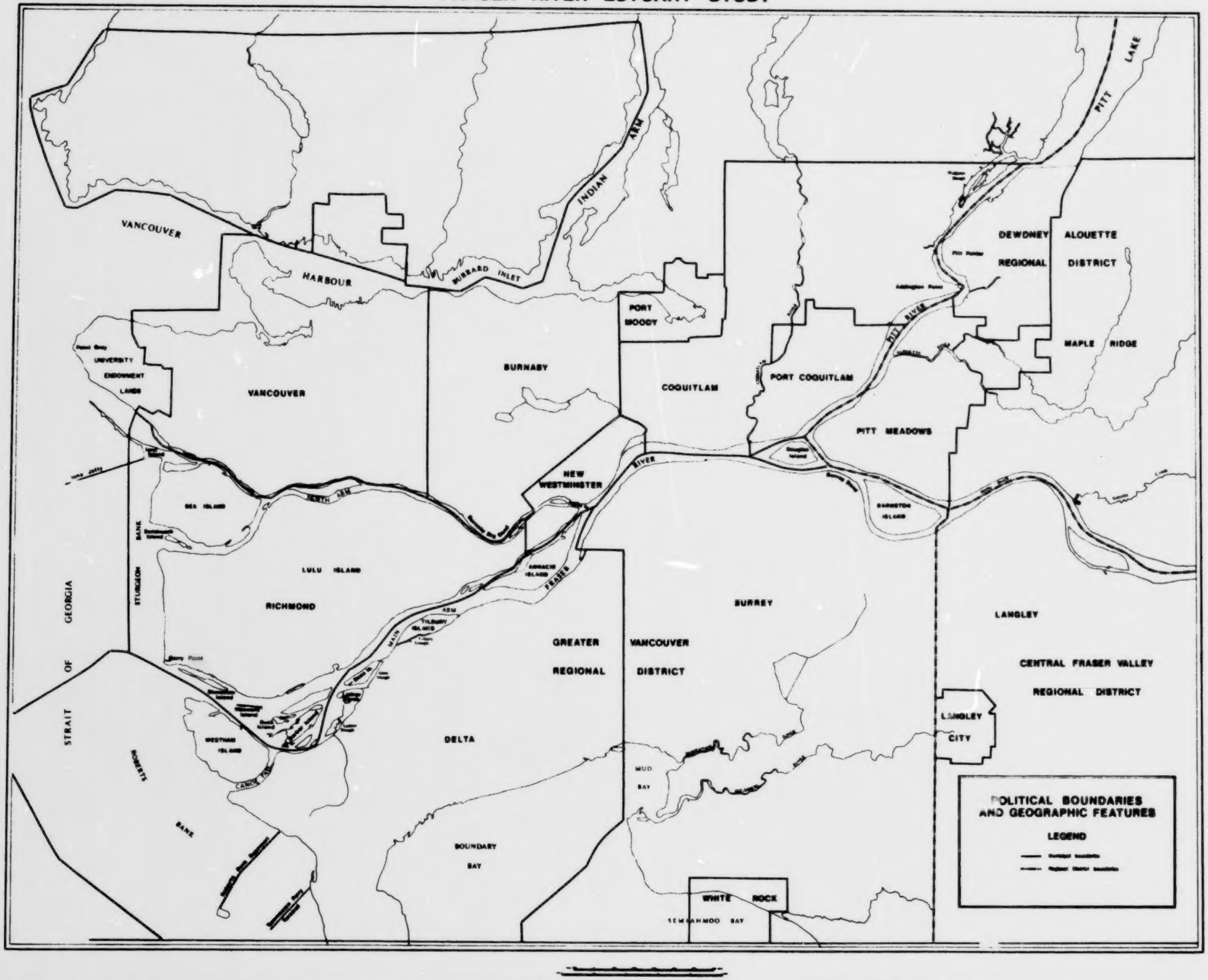
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PITT RIVER
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MAPLE RIDGE
PITT MEADOWS
NEW WESTMINSTER
RIVER
NORTH ARM
SEA ISLAND
LULU ISLAND
RICHMOND
STURGEON BANK
STRAIT OF GEORGIA
ROBERTS BANK
WESTHAM ISLAND
CANOE PASS
ANNACIS ISLAND
FRASER
MAIN ARM
TILBURY ISLAND
BARNSTON ISLAND
GREATER VANCOUVER REGIONAL DISTRICT
SURREY
DELTA
BOUNDARY BAY
MUD BAY
WHITE ROCK
SEMIAHMOO BAY
LANGLEY
LANGLEY CITY
CENTRAL FRASER VALLEY REGIONAL DISTRICT
POLITICAL BOUNDARIES AND GEOGRAPHIC FEATURES
LEGEND

Fraser River Estuary Study
Water Quality

Aquatic Biota and Sediments

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SUMMARY

Biota can be sampled to provide information which may indicate the quality of their environment. This report deals specifically with distributional data for algae and aquatic invertebrates and levels of metal contamination in a number of aquatic organisms and sediments. The toxicity of various effluents to biota is discussed by Singleton (1980) in a separate report. Levels of organic contaminants in the lower Fraser River environment, including biota and sediments, are discussed by Garrett (1980).

Interpreting biological data from the lower Fraser River is complicated because of the intricate nature of the estuary. Based on the limited distributional data from the riverine portion of the study area, it is concluded that the water quality of the main river channels was generally good, although the quality of the river arms was somewhat poorer than that of the Mainstem. Occasional depressed levels of oxygen in backwaters, biologically important areas, indicated that at times water quality conditions in these receiving waters may be poor. This was due to several factors including restricted water exchange in and organic enrichment of the sediments and waters of these portions of the river.

Nuisance growths of algae were not observed in any part of the riverine portion of the study area. This was despite the possiblity of enrichment due to the addition of nutrients from both the river load upstream from the study area and effluents to the study area. The absence of nuisance blooms was likely because of limiting factors in the river such as high turbidity, fluctuating water levels, intrusions of saline water and limited suitable substrates.

The benthic invertebrate populations of Sturgeon Bank and Roberts Bank are more productive and diverse by comparison to those of the lower river. The benthos of a portion of Sturgeon Bank influenced by the Iona Island STP outfall has been degraded and altered. This was due to a number of factors including low dissolved oxygen, high turbidity, siltation and high levels of nutrients in the receiving environment. Toxic components of the effluent such as metals, organic contaminants, ammonia and at times chlorine likely also contributed to the degradation of the benthos. Within the area impacted by the sewage effluent was a zone of eutrophication where algal growth was enhanced and numbers of a few species of invertebrates were large.

The total impact of various effluent types such as sewage treatment plant discharges, stormwater discharges, landfill leachates, non-permitted discharges and spills, particularly on localized areas, have not been evaluated. The effects of log debris and woodwastes on the biota of the lower Fraser River have not been assessed.

In general, levels of metals in sediments increased with increasing amounts of component fines (silt and clay) and organic carbon. These factors and the marine influence were responsible for a number of differences in metal concentrations in sediments throughout the study area. In addition to these factors, the higher zinc levels detected in sediments of the North Arm compared to other regions of the study area, were consistent with concentrations detected in receiving waters and the fact that this portion of the river receives the greatest zinc loading from effluents. Levels of lead were higher in the North Arm than elsewhere in the river and this was also related to the factors suggested above plus the loadings of lead in discharges from industry and stormwater. Levels of several metals (cadmium, cobalt, copper, iron, lead, manganese, mercury, nickel and zinc) were elevated in sediments influenced by the Iona Island STP discharge, above levels in sediments from other parts of the Banks. The contaminated sediments were believed in part responsible for the absence of certain organisms, such as the clam Macoma balthica, from an area adjacent to the outfall.

There is some evidence of metal accumulation in biota of the riverine portion of the study area, with levels in organisms falling between those detected in pristine and polluted watersheds. Certain invertebrates bioconcentrated mercury and at times zinc and copper, above levels in sediments. Levels of metals in fish, including salmonids, were not considered to be of concern. Mercury was an exception and exceeded the enforcement level of the Health Protection Branch, Health and Welfare Canada, of 0.5 µg/g wet weight in muscle tissue of certain non-migratory fish (northern squawfish, prickly sculpin, white sturgeon, largescale sucker, and peamouth chub). Mercury exceeded this level in some species from each site sampled from Hope downstream to the river mouth.

Metals are accumulated by certain biota of the Banks. Evidence shows that the Iona Island STP is one of the sources of metal contamination, but that other sources exist.

Crabs from Sturgeon and Roberts Banks contained higher levels of copper and mercury than specimens from two other sites in British Columbia, which should represent background conditions. The mean level of mercury was higher in specimens from Sturgeon Bank than from Roberts Bank and concentrations in three specimens exceeded the enforcement level for edible tissues. More information is needed on levels of arsenic in crabs of the Bank. These should be compared to ambient levels in specimens from non-impacted sites in British Columbia. Clams present near the Iona Island STP outfall bioconcentrated copper, zinc and mercury above levels in the sediments.

Levels of metals in juvenile starry flounders and juvenile chinook salmon were monitored. Concentrations were considered low. Mercury and arsenic levels were higher in the flounders than in the chinook. Levels of mercury were below the enforcement level for edible tissues, although it is unlikely that juveniles would be taken as food.

It is recommended that steps be taken: to preserve or improve the quality of backwaters of the river to protect biological populations; to protect biota of the Banks from further degradation or alteration; to implement a comprehensive source control program for metals discharged to the study area; and to upgrade treatment of sewage at the Iona Island plant (through further treatment and discharge from the existing outfall or by relocating the outfall point to Georgia Strait), to allow rehabilitation of a degraded portion of Sturgeon Bank. Continued research and special studies should be undertaken to fill data gaps. These include an evaluation of the impacts of various discharges such as non-permitted effluents, stormwater and the major sewage treatment plants (in addition to Iona) on the receiving environment, including the biota. A comprehensive monitoring program is recommended for further assessment of metal contamination in the study area. These studies and monitoring should be coordinated with other sampling efforts.

Singleton (1980) has made recommendations regarding evaluation of acute toxicity in the study area and Garrett (1980) has made recommendations regarding toxic organic contaminants.

PREFACE

The Fraser River Estuary Study was set up by the Federal and Provincial Governments to develop a management plan for the area.

The area under study is the Fraser River downstream from Kanaka Creek to Roberts Bank and Sturgeon Bank. The Banks are included between Point Grey and the U.S. Border. Boundary Bay and Semiahmoo Bay are also included but Burrard Inlet is not in the study area.

The study examined land use, recreation, habitat and water quality, and reports were issued on each of these subjects.

Since the water quality report was preliminary, a more detailed analysis of the information was undertaken by members of the water quality work group. As a result, eleven background technical reports, of which this report is one, are being published. The background reports are entitled as follows:

- Municipal effluents.
- Industrial effluents.
- Storm water discharges.
- Impact of landfills.
- Acute toxicity of effluents.
- Trace organic constituents in discharges.
- Toxic organic contaminants.
- Water chemistry; 1970-1978.
- Microbial water quality; 1970-1977.
- Aquatic biota and sediments.
- Boundary Bay.

Each of the background reports contains conclusions and recommendations based on the technical findings in the report. The recommendations do not necessarily reflect the policy of government agencies funding the work. Copies of these reports will be available at all main branches of the public libraries in the lower mainland.

Five auxiliary reports are also being published in further support of the study. These cover the following subjects:

- Site registry of storm water outfalls.
- Dry weather storm sewer discharges.
- Data report on water quality.
- Survey of fecal coliforms in 1978.
- Survey of dissolved oxygen in 1978.

Copies of these reports will be available from the Ministry of Environment, Parliament Buildings, Victoria, British Columbia.

To bring this work together the water quality work group is publishing a summary report. This document summarized the background reports, analyzes their main findings and presents final recommendations. Some of the recommendations from the background reports may be omitted or modified in the summary report, due to the effect of integrating conclusions on related topics. Copies of the summary report are in public libraries, and extra copies are available to interested parties from the Ministry of Environment in Victoria.

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CHAPTER 1 INTRODUCTION

The population of the lower Fraser Valley, and particularly of the greater Vancouver area, has grown steadily over the last 100 years. The lands and waters of the lower Fraser Valley are used in a number of ways Fraser River Estuary Study (F.R.E.S.), Land Use and Transportation, Recreation and Habitat Reports, 1978. Shipping and boating traffic is heavy throughout the study area. Log booms are stored along much of the foreshore of the river arms and must be moved by tugboat from the booming grounds to sites of log use, mainly through the North Arm. Perhaps of most significance to the water quality are the numerous discharges entering the river. Not listed in any particular order, these include effluents from agricultural land, urban land, and industrial land; industrial and municipal effluents; landfill leachates; miscellaneous non-permitted discharges, illegal discharges and accidental spills.

The Fraser River and tributaries provide habitat for the spawning and early development of five species of salmon. The drainage supports the most lucrative salmon fishery of the Pacific west coast, but it is also used by man in a variety of other ways, as mentioned above, which may conflict with the fishery. In 1976 the gross value of the salmon commercial catch was estimated at 86 million dollars, retail value. The value of the commercial catch is expected to reach 2.5 billion dollars in 70 years, based on 1979 prices and if production increases due to the salmonid enhancement program, the value is estimated to exceed 3.4 billion dollars (F.R.E.S., Habitat Report, 1978). Sports fishing is an important recreational activity in the region (F.R.E.S., Recreation Report, 1978). Crabs, herring and eulachon are also fished commercially in the estuary.

This report reviews biological information and attempts to relate the state of aquatic biological communities to water quality conditions and, where relevant, to specific discharges. It is an attempt to determine whether the various uses of the Fraser River have an effect on the biota, including those taken commercially. To prevent an overlap with F.R.E.S. Habitat Report (1978) this report excludes data relevant to birds and mammals, but does include selected information on fish.

Information on the distribution and ecology of algae and aquatic invertebrates in the river was collected mainly prior to 1975. This and similar information from the mudflats (Sturgeon Bank and Roberts Bank) are discussed in Chapter 2. Chapter 3 includes more specific information.

Measures of metals in biota are valuable monitors of the degree of contamination in the environment. A review of metal levels in sediments is made as an indication of the degree of contamination in this component of the environment and because contaminants can be released from sediments to the water column or directly to benthic organisms and subsequently to the rest of the food web. Data covering levels of metals in biota and sediments are discussed in Chapter 3. Garrett (1980) reviews levels of organic contaminants in sediments.

The relationship between upland and foreshore habitat alteration and destruction and water quality is an extremely important area of concern in the estuary. Discussion of this topic was considered beyond the scope of this report although there have been several impacts of this nature in the study area of the Fraser River. Some aspects of this topic have been considered in the F.R.E.S. Habitat Report (1978). Closer communication between work groups would result in better coverage of such topics which lie between those specified by the terms of reference for several groups.

Two other background reports of the Water Quality Work Group discuss biological data. Singleton (1980) reviews acute toxicity information related to effluents and Garrett (1980) reviews levels of organic contaminants in aquatic biota and the possible effects organic compounds may have on them.

The map of the main river and part of the mudflats has been divided into a number of reaches (R1-R26; Figure 1), to aid discussion of sampling locations (Drinnan and Clark, 1980; Churchland, 1980). These reaches are often referenced in this report.

In this report the term "Banks" refers to Sturgeon and Roberts Banks seaward from the foreshore of the lands of the estuary to the point where the flats drop off. "Banks" is often used interchangeably with the term "mudflats". The term "river" refers to the aquatic portion of the Fraser River extending from the upstream study boundary at Kanaka Creek downstream to the Banks. Foreshore and upland habitat are not included in this definition. For discussion purposes the river has been divided into two categories, the "main river channels" which refers to those parts of the river in the main stream of flow and "backwaters". "Backwaters" is a loose term to encompass areas of slow moving water including sloughs, side channels, back channels and backwashes of the main channel.

The core study area is defined in the preface. The water quality of tributaries to the Fraser River has not been assessed. Although the water quality of the tributaries may in general have little impact on the water quality of the Fraser River, it will have a significant impact on the fishery of the Fraser because the tributaries are important rearing grounds for salmonids.

CHAPTER 2 BIOTA AND WATER CHEMISTRY

2.1 Introduction

Food webs of aquatic systems are complex biological interdependencies. Fish depend on primary producers such as phytoplankton, algae and aquatic vascular plants for food, and are frequently reliant on consumers, including zooplankton and epibenthic and benthic invertebrates. Organic debris and detritus originating from natural sources such as upland, marshland and aquatic plants, and anthropogenic sources such as log booms are significant sources of nutrients for microbiota including bacteria, fungi and protozoa. Some aquatic invertebrates feed on organic debris and the associated microbiota. They may also graze on algal or vascular plants or consume smaller invertebrates. Invertebrates are an important part of the diet of many fish and some birds and small mammals.

Maintenance of the integrity of the food web is necessary to support a viable fishery. Alteration of any component may affect the others including the higher consumers. For example, destruction of marshland and upland vegetation will result in a reduced contribution of organic detritus to the system, aside from implications for habitat loss. Details of habitat loss are not considered by this report. Overgrazing of plants at the primary level by invertebrates could cause an imbalance in the web, as would excessive predation on primary consumers by secondary consumers, such as carnivorous invertebrates and fish. These kinds of imbalances may result in pressures on the system producing vigorous competition for food and habitat.

Alterations to the biotic community can also be caused by physical and chemical factors. Some factors are naturally occurring phenomena and are extremely significant in a complex estuary. Others are controlled by anthropogenic influences. Of particular interest in urban watersheds are those factors which may be affected by discharges to the receiving waters.

Distributions and activity of organisms are often studied as indicators of the quality of their habitat (Albright and Wentworth, 1973; Cairns, 1978; Cairns, 1974; Blum, 1956; Gannon and Stemberger, 1978; Goodnight, 1973). Information of this type will be assessed to determine whether there is any relationship between these data and water quality, and to determine which parameters are important to aquatic biological communities.

2.2 Environmental Factors and Trends in Biological Communities

2.2.1 Parameters Affected by Anthropogenic Influences

2.2.1.1 Oxygen

In the aquatic environment, the amount of biologically available oxygen can be governed by a number of factors controlling solubility including water temperature, depth and salinity, and factors controlling replenishment such as river flow, the degree of mixing of water masses and photosynthesis by aquatic plants. Chemicals (inorganic and organic) in effluents may be oxidized when they enter receiving waters, reducing or at times depleting oxygen levels. Microbiota, including bacteria utilize carbon as an energy source. When the level of organics is increased in receiving waters and sediments, due to sewage discharges or accumulation of debris from sources such as logs and other vegetation, the bacterial populations increase in number. Large numbers of aerobic microbiota place an unaccustomed demand on the oxygen supply. Organic materials, including decaying plant and animal matter and compounds originating from various discharges, entering the receiving waters in a reduced state, consume oxygen as they become oxidized. All these demands on oxygen are extremely important, particularly where waters are poorly flushed and there is slow or limited exchange between bottom layers and the atmosphere.

There are a number of methods of reporting oxygen data. One is according to concentration. The maximum solubility of oxygen, originating from the atmosphere, in water under ideal conditions and $0^{\circ}C$ is about 14 mg/L. This amount is reduced when temperature and salinity increase (Gameson and Robertson, 1955). Percent saturation is a relative measure because it accounts for temperature and salinity. Under warm water conditions, the concentration of oxygen may be 7.0 mg/L or less while the percent saturation may remain at 100 percent. Most oxygen data for the receiving waters of the Fraser system have been reported as concentrations (mg/L) (Drinnan and Clark, 1980), as is often the convention with water chemistry of studies (Davis, 1975). This unit of measurement will subsequently be used in this report.

(a) Criteria

The lower Fraser River provides habitat for juvenile and adult chinook, chum, pink, sockeye and coho salmon and other salmonids (Northcote, 1974), therefore the maintenance of an oxygen-rich regime is extremely important. Various oxygen criteria for rivers and streams are in use by different agencies, but the most relevant documentation of oxygen standards for the protection of Canadian fish species is that by Davis (1975). If oxygen requirements of salmonids are met it is likely that most other fish species will be protected (Davis, 1975).

Davis (1975) established dissolved oxygen criteria for the protection of a number of kinds of fish. He took into account the critical partial pressure of oxygen and oxygen content in water, and the effects of temperature both on solubility of oxygen in water and on the metabolism of organisms. The criteria are expressed according to a number of conventions (Davis, 1975), but will be reported here as concentrations, to maintain consistency with Drinnan and Clark (1980).

Davis (1975) expressed criteria for dissolved oxygen as level A, B or C. Level A represents ideal oxygen conditions and includes a margin above the concentration at which average fish begin to show stress responses (the incipient oxygen level). Level B values are oxygen concentrations at which average fish exhibit response or are stressed (slightly below the incipient level). Level C values are concentrations at which most fish in a class will show stress or response, and these are below the incipient response level for average fish. Criteria for these levels for freshwater salmonids, salmonid larvae and mature eggs, and anadromous marine species including salmonids are listed in Table 2-1.

Guidelines for the protection of aquatic invertebrates have not been established due to the lack of information on this topic. This is a difficult concept to develop because invertebrates may live in the water column, above the sediments or in them and can undergo anaerobic metabolism for several hours, at times of hypoxia (conditions of low oxygen availability) or anoxia (conditions of no oxygen availability) (Hochachka and Somero, 1973). Furthermore, little is known of their oxygen requirements during embryologic development. The best alternative at present may be to adopt criteria for salmonids for the protection of this group (Davis, 1975).

(b) Main River Channels

Level A criteria should be met where there is a valuable fishery, unless natural conditions prevent this. The oxygen regime of the Fraser River will be assessed according to these standards. Drinnan and Clark (1980) discuss oxygen levels and oxygen consuming materials in the receiving waters of the Fraser River using data usually collected from the main river channels. Many measurements were taken at or near the water surface, but in the main channel mixing of the waters was expected. Ninety percent of all dissolved oxygen measurements were greater than the B criteria for salmonids (6.00 - 8.00 mg 0_2/L), in all reaches except reach 19 (north of the North Arm jetty) and reach 20 (south of the North Arm jetty). In each of these cases only ten percent of the measurements were less than 7.9 mg 0_2/L (Drinnan and Clark, 1980). The occasional oxygen depressions discussed by Alexander and Bergerud (in prep.) were generally related to water salinity and temperature. Mean and median oxygen concentrations for all reaches were close to or greater than level A criteria for salmonids (7.75 - 9.75 mg 0_2/L; Table 2-1), which indicates that, for the most part, the oxygen regime of the main river channels was good, and the requirements of most organisms were met.

The diatom Achnanthes minutissima and the green algae Ulothrix zonata and Rhizoclonium hieroglyphicum were found commonly in the Fraser River (Northcote, Ennis and Anderson, 1975). They are found normally in oligotrophic, well-oxygenated waters (Hancock, 1973; Palmer, 1962). The diversities of diatoms in late summer (1972 and 1973), when oxygen levels might drop, were high (Northcote, Ennis and Anderson, 1975; Figure 2), indicating these populations were not stressed by environmental factors, including lowered oxygen concentrations.

None of the diversity indices (Shannon-Weiner) calculated from benthic invertebrate data reached 3.0, the level indicating a well balanced population not stressed by environmental parameters (Northcote et al., 1976; Figure 4). There may be several reasons for this, including stress factors imposed by the estuarine environment (refer to Section 2.2.2). Furthermore, the community sampled in the upper North Arm, reach 15 (Westwater site 5; Figures 1 and 3) was less diverse than the other invertebrate populations sampled (Northcote et al., 1976; Figure 4; Table 2-2). Decreased oxygen concentrations in reach 15 resulting from the oxygen demand of wastes in effluents discharged to that portion of the river were believed the cause of the less diverse invertebrate population (Northcote et al., 1976).

The Braid Street outfall (until October, 1975) and seven other smaller outfalls (until October, 1976) discharged combined municipal sewage to the Mainstem at New Westminster. A portion of these effluents likely entered the North Arm. Three other outfalls at Columbia, Third Avenue and Fourth Avenue discharged combined municipal sewage directly to the North Arm at New Westminster until 1977. These sewers were directed to the Annacis Island sewage treatment plant (STP), but during storms they may still overflow through the old outfalls to the river and bypass the plant.

Wood debris, wastes from log booms, stormwater and industrial discharges were also likely consumers of oxygen in the North Arm. A further result of wood waste may be smothering of the benthos, brought about by the prevention of oxygen exchange between the water column and the substrate.

There is little or no evidence to suggest that there are biological problems associated with oxygen concentrations in the water column of the main river channels, although no site specific studies have been conducted in the river. No severe oxygen depressions resulting from the addition of sewage from the Annacis Island plant have been detected in the river by routine monitoring (Drinnan and Clark, 1980). Some oxygen levels in the main channel of reaches 6, 7 and 8, downstream from the Annacis Island outfall, were lower than in reaches 4 and 5, upstream from the outfall, but 90 percent of all values in reaches 6, 7 and 8 were above 8.5 mg/L oxygen (see Figure 19 in Drinnan and Clark, 1980). Oxygen depressions were not noted downstream from the Lulu Island STP (Figure 5) (Drinnan and Clark, 1980). More information is needed regarding the dilution zones of discharges to estimate the severity of general and localized alterations to the oxygen regime. The total volume of sewage discharged and thus the total quantity of oxygen consuming materials being discharged will increase with time (Cain and Swain, 1980).

The impact of stormwater (Figure 6) on the oxygen regime of the river is unknown. Estimates approximated the BOD load from it to be about 15 000 kg/d (Ferguson and Hall, 1979), which is similar to the daily BOD load from the Annacis Island STP discharge (Cain and Swain, 1980) (Table 2-3). The load from stormwater is distributed over some 180 discharges in the study area. Further work to identify the impact of these effluents on the river within their respective dilution zones is needed.

The total BOD load discharged by industry directly to the Mainstem was relatively low (<850 kg/d), to the North Arm somewhat higher (5 320 kg/d), and to the Main Arm the highest (17 700 kg/d) (Table 2-3). The load to the Main Arm from industry was higher than the BOD load from the Annacis Island STP discharge (Cain and Swain, 1980). Most of this BOD originated from fish processing plants discharging to Cannery Channel (Swain, 1980) (Figure 7).

Of the estimated 35 wood waste dumps in the study area, about 80 percent were not regulated by permit and there are no COD data for these (Atwater, 1980). Rough calculations suggested that the total COD of the leachates was about 16 300 kg/d (Atwater, 1980) or about 12 percent of the total COD of the three major municipal treatment plants (141 700 kg/d). There are no data to indicate what effects these and other non-permitted landfills, illegal discharges or accidental spills may have on oxygen concentrations in the river. This requires further investigation to evaluate the types of discharges involved, their frequency and the severity of their impacts, particularly those of a localized nature.

(c) Backwaters

Backwaters are often poorly flushed and detritus and organic materials, including those originating from discharges, may be washed into them or introduced to them directly. Organic materials and biota, which may be in the water column or in the sediments, consume oxygen. Oxygen concentrations of backwaters can become depressed because the receiving waters may not be continuously exchanged with main channel waters. The situation can be accentuated whan the waters are stratified as is the case when heavier marine waters are washed into backwaters and cover the bottom. There is no exchange between the bottom waters and the atmosphere and little or none between water layers, allowing for hypoxic or anoxic conditions to develop, particulary in the bottom layers.

A survey carried out on a number of backwater areas indicated that at some locations oxygen levels periodically fell below 7.75 mg/L, the level A criterion for freshwater salmonids. These locations included Cannery Channel, Ladner Slough and Side Channel, McDonald Slough, Deas Slough and north of the North Arm Jetty. Data from the survey are shown by Alexander and Bergerud (in prep.) and are summarized in Table 2-4.

Habitat Protection Division have surveyed the oxygen content of Tilbury and Deas Sloughs and frequently found both hypoxic and anoxic conditions in the bottom waters (Dept. of Fisheries and Oceans, unpublished data). These backwaters are now sloughs as opposed to channels due to the filling in by sediments during the building of dykes at their upstream ends. The slow or limited water exchange in Deas Slough is made worse by the presence of a sill at the mouth of the slough. The biological significance of hypoxic conditions in these areas is under investigation by Habitat Protection Division, Fisheries and Oceans.

Backwaters, sloughs and side channels are important rearing areas for juvenile salmon (Mason, 1974). Dunford (1975) and Goodman (1975) documented that juvenile coho, chinook and chum occupy waters in the marsh areas of the lower Fraser. More recent work by Levy et al. (1979) confirmed that backwater areas of the lower Main Arm in the Ladner area are utilized by chinook, chum, pink and sockeye for cover and as feeding grounds for various periods of time extending from days to several weeks.

The major discharges discussed in the previous section may have some effect on the oxygen regime of backwaters. Localized impacts may have greater effects in areas of restricted water exchange. Localized impacts include the COD and BOD of organic debris from log booms, runoff from humus soils, stormwater leachate from dumped or landfilled material and effluents from non-permitted discharges or accidental spills. For example, some of the leachate from the Burns Bog Landfill (Figure 5) enters Crescent Slough and was responsible for a mean drop of 1.0 mg/L in dissolved oxygen in that slough (Atwater, 1980). Average levels of dissolved oxygen (4.8 mg/L, Atwater, 1980) in Crescent Slough were close to the level C criterion for freshwater salmonids (4.25 mg 0_2/L) and the leachate reduced oxygen levels further (3.8 mg 0_2/L, Atwater, 1980). Oxygen content was also depressed in ditches within the landfill site (Atwater, 1980).

Evidence suggests that backwaters, including side channels and sloughs are sensitive habitat and should be protected against further degradation of water quality, particularly in view of the restricted water exchange in them which contributes to hypoxic conditions. Small tributary drainages to the Fraser River are also important biological habitat, but were not included in the study area. Non-permitted and accidental discharges, of a miscellaneous nature, to tributaries occasionally have resulted in oxygen depressions producing fish kills. This subject is considered in Section 2.3.

(d) Banks

Low dissolved oxygen concentrations have been detected on Sturgeon Bank in an area influenced by the Iona Island STP discharge. The suggested level A oxygen criterion for marine salmonids is 9.0 mg/L. Concentrations were often less than this in the receiving waters (depth 1 m) up to 1.5 km west and south of the outfall (Figure 8; B.C. Research, 1973 and 1975). Levels ranging from 4.5 to 6.0 mg/L were detected close to the outfall and in the portion of the sewage channel closest to the outfall (B.C. Research, 1975). Otte and Levings (1975) recorded concentrations as low as 1.5 mg/L adjacent to the outfall, slightly south of it and in the sewage channel.

Depressions in oxygen concentration were likely responsible in part for the absence of invertebrates immediately adjacent to the Iona Island sewage outfall and for reduced numbers more distant in the zone of greatest impact and in the zone of degradation (about 1.5 km west and 1.2 km south) (Figures 8a and 9) (B.C. Research, 1973, 1975 and 1977). The zones of impact extended further west in the sewage channel than on the mudflats south of the channel (Figure 8a). The low oxygen values did not meet the level A criterion for anadromous marine fish (9.0 mg/L) and were below or close to the level C criterion for anadromous marine fish (4.0 mg/L). The impact of this on the fishery (fish and crabs) has not been determined.

The sewage effluent discharging into receiving waters at a high tide or mixing with receiving waters on an incoming tide had a considerable COD in 1975 (mean value 54 000 kg/d) as well as BOD (mean value 38 500 kg/d) (Cain and Swain, 1980) and likely directly depressed dissolved oxygen in the receiving waters. Organic matter from the sewage outfall has accumulated in the sediments and was also suggested responsible for depleting the oxygen level in incoming sea water (Otte and Levings, 1975). Respiration by aerobic bacteria and periphytic algae on the mudflats was proposed as another major factor in lowering oxygen levels in receiving waters during an incoming tide (B.C. Research, 1975).

2.2.1.2 Nutrients

The nutrients discussed here are the main elements necessary to support primary producers and decomposers. Basically these are nitrogen and phosphorus, in their various chemical forms, as well as silica and carbon. Drinnan and Clark (1980) have discussed these parameters in detail with the exception of silicates for which there were limited data. Pertinent information from their report is summarized and used in the following discussion.

Phosphorus is often considered to be the controlling nutrient for plant growth in river systems (Hynes, 1970a), while nitrogen may be considered such in the marine environment (Antia et al., 1963). Both phosphorus and nitrogen must be available for growth, but when the nutrient in limited supply becomes abundant, plant growth may proceed quickly, resulting in algal blooms. Algal blooms can become a nuisance by deteriorating the aesthetic quality of a water system, degrading water quality (through excretion of metabolites, through decay and subsequent lowering of dissolved oxygen levels), by altering or limiting habitat for other organisms and by interfering with the use of water by industry. Alternately, limited or controlled stimulation of primary production can provide the basis for enhanced production through the rest of the food web.

(a) Nitrogen and Phosphorus in the River

Table 2-3 summarizes the loadings of phosphorus (total) and nitrogen (total) to the river from various sources. The sewage treatment plants, particularly the Annacis Island and Iona Island plants, were the most significant anthropogenic sources of nutrients to the study area. Estimates of loadings from stormwater show that the total of these effluents may also be a significant source (Table 2-3). By comparison, the contributions from landfill leachates and industrial discharges were small and unlikely to have a significant impact on the main river channels. They may, however, have localized effects in small tributaries, drainage ditches or backeddies where they enter the river (Atwater, 1980; Swain, 1980). Diverting leachates from landfills to the sewer would prevent local problems. This may tend to raise the loadings of nitrogen discharged from the plants per day (Atwater, 1980). It should be noted that loadings of nitrogen and phosphorus from anthropogenic sources to the lower Fraser River are increasing with time (Drinnan and Clark, 1980).

Mean concentrations of nitrate nitrogen in reaches 7, 8, 10, 11 and 12 of the Main Arm and in reaches 14, 17 and 18 of the North Arm were higher than the mean concentration at Pattullo Bridge (R3) on the Main Stem. Similarly mean concentrations of orthophosphate phosphorus in reaches 8, 9, 10 and 11 in the Main Arm and reaches 16, 17 and 18 in the North Arm were above the mean detected at Pattullo Bridge (R3) (Figures

23 and 26 in Drinnan and Clark, 1980). Drinnan and Clark (1980) suggest that elevated phosphorus levels low (downstream) in the river arms may be due to intrusion of marine waters.

Mean concentrations of nitrate nitrogen in the lower portions of the arms of the Fraser were greater than levels detected in the Thompson system downstream from sewage treatment lagoons and a pulp mill (Table 2-5). Growth of periphytic algae was prolific in that portion of the Thompson, downstream from the city of Kamloops, and considered a problem (Langer et al., 1975). Mean levels of ammonia in the downstream portion of the Main Arm were higher than in two oligotrophic rivers, the West Kettle and the Elk (Table 2-5) (Kootenay Study, 1977; 1978). Concentrations of orthophosphate phosphorus can be compared to dissolved phosphorus, although the dissolved form includes both orthophosphate phosphorus and dissolved organic phosphorus. In the downstream portions of both the North and Main Arms, mean concentrations of orthophosphate phosphorus were higher than levels of dissolved phosphorus detected in the Thompson system downstream from the sources of nutrients. In the Thompson the presence of algal blooms was related to the increase of biologically available phosphorus originating from the Kamloops sewage treatment lagoons and a pulp mill (Federal-Provincial Thompson River Task Force, 1975). The blooms altered the South Thompson River at Walhachin aesthetically and were also believed responsible for alterations to the invertebrate community due to changes in food availability, habitat and water quality. Subsequent interferences with the fish communities due to altered habitat and competition for food and habitat from the increased numbers of invertebrates were anticipated (Langer et al., 1975).

Little work has been conducted on the effects of nutrients on primary productivity in the lower Fraser River. A survey conducted from 1972 to 1973 indicated that most riverine algae were attached forms and most algae collected as phytoplankton originated from the periphyton (Northcote, Ennis and Anderson, 1975). Dense growths of algae were not observed in the river and most periphytic communities were composed of a high number of species (Northcote, Ennis and Anderson, 1975).

Nuisance algal blooms could be expected in the downstream portions of the Fraser River arms, based on the water chemistry discussed above. This response was not realized. There are differences between the Thompson and Fraser River systems. The lower Fraser is highly turbid (high in suspended solids) limiting light availability; it undergoes daily fluctuations in water levels due to tidal change resulting in lengthy periods of exposure and fluctuations in water salinity and it generally has unsuitable substrate for algal growth (Northcote, Ennis and Anderson, 1975; G.L. Ennis, personal communication). These conditions likely mask or limit algal growth (Northcote, Ennis and Anderson, 1975).

Cladophora glomerata was a dominant alga in the North and Main Arm. It is often found in eutrophic waters and its growth is apparently controlled by levels of phosphorus (Pitcairn and Hawkes, 1973). Northcote, Ennis and Anderson (1975) related its presence to the numerous sewage discharges, including municipal (New Westminster, Ladner, Lulu), stormwater and industrial effluents, entering the river (Figures 5, 6 and 7). Their conclusions were based on information from other watersheds (Butcher, 1946; Bellis and McLarty, 1967; Stockner et al., 1972; and Pitcairn and Hawkes, 1973).

(b) Nitrogen and Phosphorus on the Banks

Nutrient enhancement of primary productivity has been observed near the Iona Island sewage outfall. An increase in biomass of algae was noted on the jetty approximately two to four km away from the outfall (Table 2-6). This was related to increased levels of phosphorus and nitrate nitrogen detected in the receiving waters (Figures 11 and 12). Algae were not present close to the outfall despite high levels of nitrogen and phosphorus in the receiving waters, due to a number of factors including high turbidity and siltation, which reduced the levels of light below minimum intensities for growth (Burrows, 1971; B.C. Research, 1975). Total phosphorus and Kjeldahl nitrogen in the sediments of the sewage channel immediately adjacent to the outfall and some distance away (1.8 km) were high (Figures 11a and 12a). The upper range for phosphorus was 2 028 mg/kg and for nitrogen 6 185 mg/kg (B.C. Research, 1975). Mean concentrations in sediments from transects running south from the sewage channel generally decreased in a westerly direction away from the outfall. Periphyton was most abundant on the mud 0.75 to about 1.0 km away from the outfall in the zone of eutrophication (Figure 8a) where turbidity and siltation did not inhibit growth (Otte and Levings, 1975).

Considerable numbers of bivalves, including the species Mytilus edulis (mussels), Macoma inconspicua and Cryptomya californica (clams), and crabs, Cancer magister (Dungeness) were noted on the mud flats peripheral to the zone of degradation (Brown et al., 1977). A large population of rats (Rattus norvegius) was also observed at Iona Island, using the cover afforded by the jetty, foraging in the intertidal zone and feeding on mussels (Brown et al., 1977). Raptorial birds were noted preying on the rats, and other birds (scaups, grebes and herons) were also observed feeding in the area near the outfall. This expanded, but likely unstable, animal community on Sturgeon Bank was related to local enrichment in the environment resulting from the Iona Island discharge (Brown et al., 1977).

Productivity in Georgia Strait and the effect of the Fraser River discharge on it have been of interest (Parsons et al., 1969; Stephens et al., 1969; Parsons et al., 1970; Takahashi and Parsons, 1972). Recently, concern has arisen regarding the possibility of eutrophication in the strait due to the Fraser River discharge, but more particularly due to an increase in sewage inputs to the river over the last ten years (Stockner et al., 1979). A three fold increase in primary production from 1967 to 1977 was observed by Stockner et al. (1979). This is a topic of considerable debate due to the actual measurements of increased primary production and to suggested sources of nutrients for primary production (Parsons et al., 1980; Clark and Drinnan, 1980; Stockner et al., 1980). Further investigation is required to provide conclusive evidence to resolve this debate.

Increased primary production can have beneficial results on higher consumers as shown by the Lake Fertilization Study (LeBrasseur et al., 1978), but eutrophy can also lead to changes in communities of primary producers and subsequent imbalances in the food web.

(c) Carbon

Carbon in certain chemical forms is an essential nutrient to all levels of the food web. Heterotrophs as well as autotrophs are important in making carbon available to the rest of the food web. In addition to breaking down organic matter to the correct particle size for consumption by various higher consumers, heterotrophs can transform soluble carbon into particulate form and store it in a chemical state that is available to consumers. Invertebrates can thereby gain access to another energy source. Bacterial growth is dependent on the amounts of carbon, nitrogen and phosphorus available. Increases in potential heterotrophic activity measured as the rate of uptake of glucose are directly proportional to increases in soluble carbon, particulate carbon and particulate nitrogen in the Fraser River (Albright and Wentworth, 1973).

The data from the Fraser River for dissolved carbon in receiving waters are limited, but results from the lower Main Arm suggest that almost all the total organic carbon measured was dissolved (K.J. Hall and R.W. Drinnan, personal communication).

Values of total organic carbon showed no significant increase in the downstream portion of the river as compared to upstream from Hope (Drinnan and Clark, 1980). The potential heterotrophic activity increased downstream from McMillan Island to the North Arm at Vancouver indicating that the North Arm could support larger populations of heterotrophic bacteria than the Mainstem (Albright and Wentworth, 1973). This study and more recent work in the Fraser River with bacteria (Albright, 1975; 1977) indicates that measurements of heterotrophic activity may be more sensitive indicators of eutrophy than measurements of particular chemical parameters. Data regarding productivity and distribution of bacteria and algae could provide relevant information on the impact of loadings of nutrients to the river.

On Sturgeon Bank, organic carbon was four to ten times more concentrated in sediments up to two km west of the Iona Island outfall, in the sewage channel, than in sediments from other areas of the bank. This was also true of carbon in sediments immediately south of the outfall (B.C. Research 1973; 1975). Particulate carbon in the sediments may provide nutrition directly to invertebrates or to bacteria in the sediments.

2.2.1.3 Light Intensity and Suspended Solids

Light is a requirement for photosynthesis; it should be available in a critical range, not falling below or exceeding certain levels (Round 1965; Takahashi et al., 1973). In temperate climates a seasonal reduction in light duration coupled with other factors, diminished algal growth (Round, 1965). Further reduction of primary productivity due to insufficient light may have a deleterious effect on dependent herbivores and detritivores. Suspended particles (measured as non-filterable residues and turbidity) reduce the amount of transmitted light in the water column.

The Fraser River is more turbid than many other rivers in B.C. (Drinnan and Clark, 1980), due to the tremendous load of suspended sediments originating from channel erosion. About 20 000 000 tonnes per year of suspended sediments originating from the Fraser River upstream of the Canyon enter the study area downstream of Kanaka Creek (Luternauer, 1974). Turbidity levels fluctuate seasonally and are greater at high flow.

Non-filterable residue values are less in the study area as compared to the upstream reach from Mission to Hope because much suspended material begins to settle out in the delta (Drinnan and Clark, 1980). Downstream from Kanaka Creek, tributaries are additional sources of suspended solids, particularly during freshet, yet do not raise non-filterable residue values downstream from the Port Mann Bridge (R 2) to levels found upstream. During high flow the Coquitlam River may add up to 605 600 kg/d suspended solids to the Mainstem at the Port Mann Bridge (R 2) (Olan and Goddard, 1977). Under normal flow conditions the input of suspended solids from the Coquitlam River is about 10 000 kg/d. Much of the load during high flow has been attributed to terrestrial washout due to poor logging practices, runoff through gravel pits and slides in the area (Northwest Hydraulic Consultants Ltd., 1976).

Although the Fraser River is highly turbid, potential impacts on the environment resulting from suspended solids in discharges cannot be completely ruled out. The major single anthropogenic source of suspended solids discharged to the Main Arm is the Annacis Island STP, discharging mean loadings of 8 000 to 11 000 kg/d suspended solids. It contributed an additional two percent suspended particles to the river during low flows and an additional 0.01 percent at high flow (Cain and Swain, 1980). Belkin Packaging discharged an estimated 11 000 kg/d suspended solids and Western Canada Peat discharged intermittently almost twice that amount (22 000 kg/d) to Burns Bog (Swain, 1980). Other much smaller discharges of suspended solids include the Lulu Island STP (2 000 kg/d), the Rayonier sawmills in New Westminster (7 000 kg/day) and at Mitchell Island (4 000 kg/d) and Dow Chemical (4 000 kg/d) (Swain, 1980). It has been estimated that leachate of the numerous wood waste landfills in the study area contributed total solids loadings of 3 340 to 9 860 kg/d (Atwater, 1980).

It is unlikely that an increase in suspended solids from all anthropogenic sources of approximately two to five percent (based on data in Table 2-3) in the Fraser River would interfere with primary productivity of such a turbid system. The additive effects of particulates on accretion of the Banks or the impacts of the kind of particulates in the discharges on habitat are unknown. The kinds of particles introduced to the suspended load from effluent discharges are probably unlike those orginating from natural sources and could alter the substrate. Particulate material in effluents is often very fine (in the size class of silt-clay), organically enriched and high in absorbed contaminants. Garrett (1980) discusses levels of PCB's in sediments immediately adjacent to (1.5 µg/g) and in the vicinity of (1.0-1.3 µg/g) the outfall of Belkin Packaging Ltd. These accumulations of PCB's in the sediments were due to significant levels discharged in sludge from Belkin Packaging Ltd., accounting for the suspended solids load indicated previously. It is likely that these level of PCB's in the sediments have an impact on the biota of that portion of the North Arm (Garrett, 1980). The sludge from Belkin Packaging Ltd. is currently being recycled to prevent further discharges of PCB's to the river (Swain, 1980). However, due to the persistent nature of these organics, contamination will likely be in the environment for some time. Garrett (1980) also suggests that organic contaminants in sediments of drainage ditches from several industrial properties such as Coast Laminated Timber and the Old Later Chemicals yard may enter and contaminate the Fraser River sediments.

The kinds and amounts of suspended particles in effluents are likely of importance to sediments of backwater areas in the river or in the zones of settling on the Banks. The zone of influence of the Iona Island STP outfall is an area where the substrate has been altered by suspended solids in the discharge. There is a concern that the balance of accretion and erosion taking place on the seaward slope of the banks could be altered by the addition of particulates from various anthropogenic sources (F.R.E.S., Habitat Report, 1978).

The marine waters of the Banks are less turbid than the river. Suspended solids in the Iona Island STP effluent have had an impact on the primary productivity of a portion of Sturgeon Bank (B.C. Research, 1973; 1975).

Algae were absent from rocks close to the Iona Island outfall, but some distance away (about 0.5 km), two "hardy" genera (Enteromorpha and Ulva; Table 2-6) were present. This distribution was in part attributed to reduced light intensity caused by silt in the discharge (B.C. Research, 1975). Two other algal genera (Fucus, Porphyra; Table 2-6) appeared on the jetty about one km away from the outfall. Their absence any nearer to it is partially attributed to decreased light intensity, but is also attributed to oxygen levels and various contaminants, such as metals and at times chlorine in the receiving waters (B.C. Research, 1975).

Colour or stain in receiving waters can also impede light transmittal. True colour measurements in the receiving waters of the study area generally ranged from 5 to 40 and in the Main Arm from 5 to 70 (Clark et al., in prep.). Drinnan and Clark (1980) felt that the higher range from the Main Arm was an artefact due to sampling intensities downstream from Annacis Island during freshet. The greatest discharger of true colour is the forest industry. True colour information is not available for all discharges. The effluent of Belkin Packaging, a paperboard mill, (downstream from R14) contained a maximum of 50 relative color units, the effluent of Scott Paper, a fine paper mill (R14), a maximum of 660 relative units and the effluent of Lamford Cedar Products, a sawmill (R3), a maximum of 1 600 relative units (Swain, 1980). Leachates from wood waste piles are also stained, but data on these are not available. The effect of these discharges on primary productivity has not been documented for the Fraser River, but it is likely that the impact in small tributary drainages or backwaters would be greater than in the main river channel.

It has been suggested that coal dust, intermittently entering the waters near the Westshore Terminals on Roberts Bank, has the potential to interfere with primary productivity (Pearce and McBride, 1977).

2.2.1.4 pH

Drinnan and Clark (1980) discuss pH in the receiving waters of the Fraser River in some detail. Generally the pH in the main river channels ranged from 7.0 to 8.0 units. On one occasion (April, 1978) some acidic values (5.8-6.8) were detected near the south shore of the North Arm in the New Westminster area (R14). This was attributed to a possible combination of factors including slightly acidic stormwater discharges, industrial discharges and some unidentified intermittent discharge (Drinnan and Clark, 1980). A number of industries at times having fairly acidic effluents (<5.0 units), discharge to the upper North Arm. These include Belkin Packaging Ltd., Scott Paper Ltd., MacMillan Bloedel Ltd. (sawmill), and Tree Island Steel Co. Other low values (<6.0) were detected in the lower North Arm (R18), including McDonald Slough, in Cannery Channel (R12), Deas Slough and Tilbury Slough. Specific sources responsible for these values were not discussed, but much of the land drainage in the delta where peat bogs (humic soil) are present, is likely acidic.

Acidic waters are known to affect biological populations. Values of 5.6 to 5.9 units, persistent over several days (8+) are known to reduce the numbers of species of phytoplankton (Yan and Stokes, 1978). More acidic values (4.0-5.0) reduce biomass of phytoplankton (Yan and Stokes, 1978) and cause high mortalities in the early developmental stages of juvenile salmonids in freshwater (Schofield, 1976). Acidity of receiving waters can also affect the solubility of other contaminants, such as metals.

Drinnan and Clark (1980) do not document the detection of significantly alkaline waters in the study area, but Langer (personal communication) reports that receiving waters adjacent to a concrete batch plant on Duck Island (R22) had a pH of 9.0 units. This may be a common problem in the vicinity of concrete batch plants, which do not come under permit because there is no single effluent draining the plant or yard. Runoff from the yard and direct dumping of concrete and washwater to the foreshore or receiving waters result in raised alkalinity of the receiving waters. Drinnan and Clark (1980) indicate that the Fraser River has a very poor buffering capacity for alkaline discharges.

Both Lafarge Cement, on the north side of the Main Arm downstream from Annacis Island (R8), and Lafarge Concrete, on the North Arm, north of Mitchell Island (R16), discharge effluents which at times exceed 10.0 pH units. The pH of effluents of Tree Island Steel (R14) and Titan Steel, on the Main Arm upstream from Gunderson Slough, at times exceeded 10.0 units (up to 12.0). The pH of some effluents from forest industries may also exceed 10.0 units. Such industrial sources include Weldwood Canada Ltd. (sawmill and plywood plant) discharging to the Mainstem (R4), Lamford Cedar Products, discharging to the Mainstem (upstream R4), Scott Paper Ltd. discharging to the North Arm (R14) and MacMillan Bloedel Packaging Ltd., discharging to the North Arm (downstream R14) (Swain, 1980).

Alkaline freshwaters are known to affect biota adversely and unchecked continuous discharges at high pH will likely interfere with organisms in the Fraser River. Freshwaters ranging from 9.2 to 10.8 pH units are known to be lethal to non-salmonids and waters of 9.5 to 9.8 pH units have been shown to be lethal to salmonids continuously exposed to these conditions for several days (Daye and Garside, 1980). Young brook trout exposed to waters of pH 9.5 for about 7 days suffered sublethal effects (Daye and Garside, 1976). Daye and Garside (1980) confirmed suspicions that waters of pH 9.0 to 9.5 units adversely affect development in Atlantic salmon alevins.

The pH of the Annacis Island STP effluent and Lulu Island STP effluent usually ranged from 6.0 to 8.0 units. The pH of the Iona Island STP effluent was often in this range, but fell below 6.0 units and exceeded 10.0 units in 1975 (F.R.E.S., Water Quality Summary Report, 1979).

2.2.2 Parameters Affected by Estuarine Conditions

2.2.2.1 Salinity

Saltwater from the Strait of Georgia extends into the lower reaches of the Fraser River, producing an estuary. This condition influences the nature of bacterial, plant and animal communities in the study area. At high tide and low flow conditions, a salt wedge may extend up the Main Arm as far as the bifurcation at New Westminister. The penetration of a salt wedge into the North Arm, upstream from Mitchell Island, is not commonly acknowledged, but elevated chloride levels have been detected in that portion of the river (Drinnan and Clark, 1980; Compare R5, R14 and R15). Saltwater reaches the upper portion of the North Arm less frequently than the upper part of the Main Arm. Tidal effects, such as changes in the level of water, are observed well up into the Mainstem. The salinity of the waters of the lower river and Banks fluctuates with tidal height and river runoff as described in detail by Ages (1980).

All organisms have different tolerances to saline or fresh water and levels of tolerance vary with organisms' age, sex and ability to acclimate. Subsequently, downstream changes from fresh to salt water will result in downstream changes in biological communities. It has been suggested that bacteria and blue-green algae are more euryhaline (tolerant to wide variations in salinity) than other algae, macrophytes or invertebrates (Stevenson and Colwell, 1973). In fact, bacterial species detected in the freshwater of the Mainstem have been found in the Strait of Georgia (Albright, 1977). Albright (personal communication) suspects this input of bacteria to the strait may be of nutritional significance to the rest of the food web. Downstream changes in species of microbes may not be as dependent on salinity fluctuations as those of "higher" organisms.

Many of the dominant green algae (Appendix 3 in Northcote, Ennis and Anderson, 1975) in the periphyton of the lower Mainstem and river arms may be considered freshwater forms with the exception of *Blidingia minima* (formerly called *Enteromorpha minima*) (Chapman and Chapman, 1973). It was collected from the Middle Arm and north of Westham Island on the Main Arm (Northcote, Ennis and Anderson, 1975), and was also notable under the Oak Street Bridge on the North Arm where the river water is frequently saline. *Achnanthes minutissima*, a diatom that can tolerate some saltwater (Patrick and Reimer, 1966), was dominant in the periphyton of upstream reaches in the

Middle Arm, in the Main Arm north of Westham Island and in Canoe Pass. *Amphipleura rutilans* and *Synedra fasciculata* are brackish water diatoms (Patrick and Reimer, 1966) and were found at the mouths of the arms (Northcote, Ennis and Anderson, 1975; Westwater sites 1, 2, 3 and 4; Figure 3). *Navicula rhyncocephala* and *Fragilaria capucina*, generally considered freshwater algae (Patrick and Reimer, 1966), were dominant further upstream in the arms (Westwater sites 5 and 6; Figure 3). The distribution of periphytic algae was partially dependent on water salinity.

Certain zooplankton, usually found in freshwater (*Bosmina* and *Diaphanosoma*), were found as far downstream as the Ladner area (Dunford, 1975; Westwater Research Centre, 1977), where salinities can be fairly high. The brackish water crustacean *Corophium* was observed in the lower portions of the arms from the Banks to a short distance upstream (Appendix 9 in Northcote *et al.*, 1976), and the brackish water mysid *Neomysis awatschensis* was found in the Mainstem (Northcote *et al.*, 1976; Levy *et al.*, 1979; Johnston, in prep.). Zooplankton sampled on the banks were largely marine forms (Tables 9 and 10 in Levings and Coustalin, 1975).

Benthic invertebrates, such as some dipteran larvae, immature mayflies and immature stoneflies, of the Mainstem (Servizi and Burkhalter, 1970) and upper arms are restricted to freshwater (Appendicies 2 and 7 in Northcote *et al.*, 1976). Many of those found in regions where fresh and saltwater mix, burrow into the substrate (chironomid larvae, oligochaetes, leeches, polychaetes). They are not subject to the same rapid fluctuations in salinity as organisms confined to the water column because the salinity of interstitial waters changes more slowly than that of the overlying waters (Chapman, 1979; Table 2-7).

A recent study of the benthos of the North Arm showed that there was a downstream change in species of invertebrates (Chapman, 1979; Chapman, 1980). At the sites furthest upstream (Figure 3) oligochaetes, particularly naidids and the tubificids *Limnodrilus hoffmeisteri* and *Tubifex tubifex*, were the dominant organisms. Freshwater chironomid larvae were also found there, particularly in the summer months. Progressing seaward, the oligochaete population was composed of naidids, but the dominant tubificid changed to *Tubificoides gabriellae* (*Peloscolex gaberellae*). Numerous amphipods, bivalves and polychaetes were found in the benthos of the outermost sites, but no chironomid larvae. Furthermore, the benthic fauna shifted up and downstream with seasonal changes in interstitial salinity, shown in Table 2-7, brought about by differences in river flow (Chapman, 1980).

Benthic invertebrates of both Sturgeon and Roberts Banks (Otte and Levings, 1975; Levings and Coustalin, 1975; B.C. Research, 1975) were either true brackish water organisms or marine intertidal organisms which tolerate freshwater flushing at low tide. Inventories of the benthic macrofauna revealed that there were more than 90 species of worms (platyhelminths, nematodes, polychaetes, oligochaetes), small crustaceans (amphipods, copepods, mysids, ostracods), crabs and burrowing shrimps (malacostracans), bivalves and snails present on the Banks. The large number of species present was partly due to conditions imposed by the saline environment (Figure 13) (Northcote *et al.*, 1976; Levings and Coustalin, 1975).

In summary, it is clear that variability in the salinity of surface and interstitial waters was partially responsible for observed changes in biological populations from the lower Mainstem of the Fraser River seaward to the Banks. This variability must be considered when relating information on biological communities to water quality changes.

2.2.2.2 Water Movement and Substrate

Water movement in the lower Fraser and on the Banks is discussed in detail by Ages (1980). Changes in elevation of the river bed in the delta, flow patterns upstream from the Fraser Canyon and water movement, all directly affect the type of substrate found in the study area. The pattern of flow of the river changes seasonally; it is high during spring runoff in May, June and July and low in December through April. Flow is also affected on a shorter time scale by precipitation. River movement is further complicated by the tidal cycle. The tides alter flow and water height as far upstream as Chilliwack (Joy, 1975). River flow and velocity also vary from arm to arm and reach to reach, depending on river channel morphology.

Planktonic, epibenthic and benthic invertebrates drift downstream with the current especially during times of high flow (Bishop and Hynes, 1969 a), but some can migrate upstream at lower flow (Bishop and Hynes, 1969 b). *Anisogammarus confervicolus* cannot maintain its position in the river against strong currents (10 cm/sec), but may be able to in backwaters (Levings and Chang, 1977). This amphipod can also remain in one place by clinging to the substrate or other cover (Levings and Chang, 1977) while *Corophium* spp. must burrow to withstand high velocity flow. Riverine and brackish water organisms resist hydrological fluctuations in diverse manners. Invertebrates of the Banks are forms adapted to extreme tidal conditions and exposure (Ricketts and Calvin, 1968).

Water movements, initiated by tidal intrusions, affect distributions of phytoplankton, but apparently have less impact on periphyton (Welch et al., 1972), which are the dominant algal group in the study area. Macrophytic algae, found on jetties of the foreshore, are morphologically suited to tidal fluctuations intensified by changes in river flow. Hydrographic features are responsible for variations in biological communities in estuaries.

The river flow at Hope normally ranges from 600 m^3/s to 8 800 m^3/s (Drinnan and Clark, 1980). This large volume of water, increased by tributaries downstream from Hope, carries with it a significant amount of suspended sediment that is deposited in the lower reaches of the river and on the Banks, wherever current is reduced. Bedload sediments also move downstream from the headwaters. Gravel is a major component of the substrate of the Mainstem upstream from Mission (Northcote et al., 1976). The substrate changes to mainly sand with some deposits of fines in the Mainstem of the study area and the river arm substrates contain varying amounts of muds (Northcote et al., 1976). The substrate of the Main Arm is composed of a large amount of sand and is mixed with silt and clay in backwater and slough areas; the North Arm appears to have a higher silt component (Northcote et al., 1976). Sand and coarse particles settle out from moving water first and silt settles only when the current is halted (McLusky, 1971). The North Arm receives 15 percent of the total volume of water leaving the Mainstem. This may result in a reduction of river velocity and a settling of fines in the North Arm (Hoos and Packman, 1974).

The Banks have been divided into three zones based on the type of substrate in each (Luternauer and Murray, 1973; Luternauer, 1974). Generally, the finer muddy sediments are located near the marsh and the more coarse sandy sediments predominate lower in the tidal zone. Sturgeon Bank is reported to have a higher silt component than Roberts Bank (Levings and Coustalin, 1975). Detailed information on the sediments of the marine foreshore area (Banks) is available (Kellerhals and Murray, 1969; Otte and Levings, 1975; Levings and Coustalin, 1975; B.C. Research, 1975; Medley and Luternauer, 1976; Luternauer, 1976a; Luternauer, 1976b; and Luternauer, 1977; Fletcher, 1976; and Swinbanks and Murray, 1977). Hoos and Packman (1974) review information pertaining to the surficial geology and soil of the lower Fraser Valley and discuss the sediments of the study area. A brief summary is also presented in the F.R.E.S. Habitat Report (1978).

As noted, the substrate of the lower portion of the river is largely sand, silt and clay. Samples of periphyton were taken from wood surfaces such as pilings and log booms in the Fraser River by Northcote, Ennis and Anderson (1975) because sand and silt are not optimal substrates for the attachment of periphyton (Blum, 1956).

The number of species of freshwater benthic invertebrates residing in a sand-silt bottom, which is unstable, is invariably small compared to the high diversity found on a cobble riffle (Pennak, 1971). In the river arms, benthic macroinvertebrates are almost entirely reduced to several species of oligochaete worms (Table 2-8) and chironomid larvae. It has been suggested that the near homogeneous condition of sand-silt substrates in estuaries produces an almost "abiotic" zone which few species colonize (McLusky, 1971).

Increases in numbers of species and biomass of macroinvertebrates on the mudflats seaward of the actual river mouth, over numbers and biomass found in the river arms were witnessed on both Banks (Northcote et al., 1976; Levings and Coustalin, 1975). This is a common trend in estuaries (Northcote et al., 1976). Figure 13 shows the numbers of species and individuals sampled from points on several transects crossing parts of Sturgeon and Roberts Banks from east to west (Levings and Coustalin, 1975). When comparing riverine populations to the marine populations, the usual concepts of species diversity should be used guardedly due to inherent characteristics of populations in estuaries. The density of benthic invertebrates was higher on Sturgeon Bank than on Roberts Bank (Levings and Coustalin, 1975). Little work has been conducted regarding the meiofauna of the mudflats, but this group is currently being investigated by Harrison (U.B.C.).

Where log booms are stored, particularly in backwaters, wood debris accumulates on the substrate. This change in substrate has the potential to alter benthic communities, but its influence has not been studied in the Fraser River. This is a significant data gap due to the large numbers of log booms which are moved and stored on the river. Some coal dust has accumulated in the sediments of Roberts Bank to the north and northwest of the Westshore coal terminal, along the terminal and Tsawwassen ferry causeways and on the beaches between these causeways (Pearce and McBride, 1977). The addition of coal dust has altered the chemical and physical nature of the substrate. Such an alteration of habitat can interfere with the benthic fauna which normally inhabit those substrates, but anomalies have not been noted to date (Pearce and McBride, 1977).

Changes in the crab catch since the construction of the jetty have not been observed, but fishermen feel that discoloration of crabs by the coal dust affects their marketability (Pearce and McBride, 1977). There is also some concern that coal dust can accumulate in crab gill lamellae causing adverse physiological effects (Pearce and McBride, 1977).

The distribution of sediments over the tidal flats is important to habitat maintenance. Construction of structures, such as jetties, on the flats can alter the distribution of sediments and subsequently habitat, as discussed in the F.R.E.S., Habitat Report (1978). The dumping of channel maintenance dredge spoil from the river to the foreward slope of the mud flats can interfere with the equilibrium between foreslope build-up and degradation.

Suspended particles discharged in sewage effluents have the potential to alter the chemical and physical nature of the substrate. At Sturgeon Bank, near the Iona Island STP outfall, the original substrate has been blanketed with fine silt which is high in organic content and levels of certain contaminants (B.C. Research, 1975). The substrate conditions are partially responsible for the absence of biota immediately adjacent to the outfall, and select for certain benthic forms which can occupy fine sediments further away, but which are still influenced by the outfall (zones of degradation, eutrophication, recovery; Figure 8a) (B.C. Research, 1975; Otte and Levings, 1975). Characteristics of the substrate are partly responsible for the lowered species diversity detected near the Iona Island STP outfall, compared to other regions of the Banks (Figures 9 and 13).

2.2.2.3 Temperature

Each aquatic species is tolerant of a particular temperature range, which is another factor controlling distributions of biota (Macan, 1962; Hynes, 1970b). Fluctuations in temperature and day length related to seasonal trends have an effect on biota and should be taken into account with any survey. The annual temperature range was generally from 4°C to 17°C in receiving waters of the lower Fraser. The coldest temperatures were detected in February and the warmest in August (Drinnan and Clark, 1980). At times of higher water temperature, heterotrophic activity is excited (Albright, 1977) and algal growth may be increased (Palmer, 1962). In temperate climates this occurs when there are longer days (more light). Green algae (e.g., Cladophora) may disappear from temperate waters, including the Fraser River, in the winter partially due to lower temperatures, but will likely reappear during July, August and September (Northcote, Ennis and Anderson, 1975).

A comparison of all water chemistry data for temperature showed that the mean temperature of the North Arm was significantly higher than the mean temperature of the Main Arm or lower Mainstem (Drinnan and Clark, 1980). This may be due to the shallower depths and lower flow in the North Arm. Temperature variability may contribute to differences in the biomass of primary producers noted among sites in the study area (Northcote, Ennis and Anderson, 1975).

2.3 Non-Permitted Discharges and Spills

It is difficult to assess the effects of non-permitted discharges, including illegal and accidental discharges or spills. There is a lack of documentation which results in uncertainty regarding frequency of occurrence, sites and nature of the discharges. This is a major data gap. Their impact is expected to be most severe in backwaters or small tributaries where the dilution is less. Accidental spills are often detected by fish kills (Department of Fisheries and Oceans; Table 2-9), although the changes in water quality which kill the fish are often not known. Other organisms may be disturbed by spills, but this would only be detected through sampling. Table 2-9 is a summary of fish kill information from the Fraser Valley area. No kills were reported in the Fraser River itself probably due to such factors as diffused surveillance over a large geographical area and inherent features of the river including large flow and high turbidity. Since 1970, eight fish kills have been reported in various tributaries of the Fraser Valley area. Whether the kills were all due to anthropogenic effects is unknown. More extensive surveillance is necessary to reveal the true magnitude of this problem and to assess its total impact in both the tributaries and the Fraser River itself.

2.4 Conclusions

There are many variables, as discussed in Sections 2.1 to 2.3, which influence biological communities. There are also many difficulties involved with interpreting distributional data in as complex an environment as the Fraser River and its estuary.

The data are limited but suggest that there may have been more environmental degradation in the river arms, largely in backwaters, as compared to the Mainstem. This may have been due to oxygen depressions and organic enrichment particularly of the sediments. Water chemistry data indicate generally high oxygen levels in the main river channels, but levels lower than those recommended for support of salmonids were occasionally detected in backwaters. Levels of nutrients in the river could have supported significant algal blooms, but this condition did not develop because of other physical and hydrological factors.

Roberts and Sturgeon Banks provide habitat for diverse invertebrate populations. The Iona Island sewage treatment plant has had a definite impact on the biota of a part of Sturgeon Bank. The result has been an alteration of biological populations. The area of greatest impact is immediately adjacent to the outfall, and there are three other zones: 1) the zone of degradation, adjacent to the zone of greatest impact, 2) the zone of eutrophication outside zone 1), and 3) the zone of recovery peripheral to zone 2). The zones have been decided upon using data from a number of reports (B.C. Research 1973; 1975; 1977; and Otte and Levings, 1975). The alteration of benthic populations has been attributed to hypoxic conditions in the receiving waters and interstitial waters of the substrate, high nutrient levels in sediments and receiving waters, high turbidity in receiving waters and siltation. Singleton (1980) has reviewed data relating to the acute toxicity of the Iona Island STP and indicates that, in general, the discharge is moderately toxic to fish. Un-ionized ammonia, anionic surfactants and possibly copper were suggested to be the major toxic components of the effluent (Singleton, 1980). The contribution of organic contaminants to the toxicity of the effluent has not been determined, but Cain et al. (1980) and Garrett (1980) indicate that a number of organic compounds are present in quantifiable amounts in the effluent. For five months in the late spring and summer the effluent is chlorinated. Chlorine itself probably contributes to the toxicity of the effluent, but may also combine with organic compounds resulting in products of environmental concern (Garrett, 1980).

Most of the biological data from the river were collected by the Westwater Research Centre from 1972 to 1974 to provide some understanding of the flora and fauna of the river and to give a general indication of the quality of their habitat. The Annacis Island STP began operation in July, 1975. This eliminated many small outfalls (some of which may still function as overflows during storm events) and the sewage was collected and sent to the Annacis Island plant for primary treatment. Many questions have arisen regarding effects on aquatic life of the lower Fraser River, resulting from the operation of the Annacis Island plant. It is impossible to derive the type of answers now sought from these data, which were collected prior to 1975.

The effects of various discharges on aquatic biota have not been investigated in the Fraser River. The discharges include stormwater, landfill leachates, miscellaneous non-permitted types and accidental spills. As with certain landfill leachates and industrial effluents, the effects are expected to be localized, but nonetheless significant. The impact of wood waste and debris on biota in the study area is a major data gap and in need of investigation.

Little work has been reported regarding chronic effects of effluent discharges on biota of the Fraser River and Banks or regarding the possibility of additive effects of several discharges of various types on biota.

Research on meiofauna has been limited (Harrison, in prep.), and there is a scarcity of information concerning these biota and microfauna in the study area.

CHAPTER 3 METALS IN SEDIMENTS AND BIOTA

3.1 Introduction

The continual addition of heavy metals to waterways has aroused the attention of individuals concerned with the protection of the environment, worldwide. There is serious concern that the accumulation of heavy metals in the aquatic environment could result in changes to its structure and stability. Much research has been directed toward this complex topic. The acute or lethal toxicity of a number of metals (e.g., Cd, Cu, Hg, Ni, Pb, Zn) to fish, particularly salmonids (Brungs, 1969; Chapman, 1978; Chapman and Stevens, 1978; Servizi and Martens, 1978), to invertebrates (Arthur and Leonard, 1970; Thorp and Lake, 1974; Andrew et al., 1977; Borgmann et al., 1978; Spehar et al., 1978; Sunda et al., 1978), to algae (Nielsen and Wium - Anderson, 1970; Erickson, 1972; Sunda and Guillard, 1976; Conway, 1978; Wong et al., 1978) and to bacteria (Albright et al., 1972; Albright and Wilson, 1974; Hamdy and Wheeler, 1978) has been demonstrated repeatedly. On the basis of such studies, acceptable levels of metals for receiving waters, and for effluents entering them, have been established for the protection of aquatic life.

Chemical and physical characteristics of water, such as pH, alkalinity, temperature, salinity, hardness and organic content markedly influence the toxicity of metals (Cairns et al., 1972; Lewis et al., 1972; Calamari and Marchetti, 1973; Chapman, 1973; Karbe, 1975; Chakoumas et al., 1979). Heavy metals are invariably discharged to waterways in mixtures and although the toxic effects of metals may not be strictly additive, joint action of toxicants has been shown (Sprague, 1964; Spehar et al., 1978).

The acute or lethal toxicity of contaminants, including heavy metals, can be measured or observed experimentally, or in the field. It is more difficult to detect the sublethal or chronic effects of metals on biota, particularly in their natural environment. Although trace concentrations of many metals are a physiological requirement, an overabundance of them can interfere with metabolism, fecundity, development and growth (Bilinski and Jonas, 1973; Thurberg et al., 1973; Anderson, 1978; Brungs, 1969; Young and Nelson, 1974; McIntyre, 1973; Pickering and Gast, 1972; Bengtsson, 1974). Certain heavy metals are also known to incite tissue and cytoplasmic abnormalities in aquatic organisms and to alter their behaviour (Sangalong and O'Halloran, 1972; Skidmore and Tovell, 1972; Mathiessen and Brafield, 1973; Bengtsson et al., 1975; Marshall, 1978;

Sullivan et al., 1978). Sublethal concentrations of metals may alter aquatic populations, but little information of this kind is available for the lower Fraser River. It has been shown that levels of metals in Sturgeon Bank sediments produced abnormal behavioural responses in the clam Macoma balthica (McGreer, 1979b) (refer to Section 3.3.3.2(c)).

In addition to general concerns over metal contamination, incidences of metal toxicity to humans have occurred when edible aquatic oganisms, including clams, crabs and fish, were highly contaminated. An example is the toxic effects of mercury in Minimata, Japan. Research into metal contamination has been stimulated in a number of locations throughout the world where a large fishery is involved, including the Fraser River.

The knowledge of chronic effects of metals on biota is incomplete owing to a lack of understanding of the chemistry of the metals and of the pathology related to them. Conclusions regarding such effects on biota of the Fraser River estuary will be extremely limited. An understanding of the degree of accumulation of metals is of special interest. Accumulation of metals at all levels of the food web is important due to the nutritional dependencies of one component on another. Bioamplification, sometimes referred to as biomagnification (McNeely et al., 1979), of heavy metals through the food web may occur, elevating the metal content in secondary consumers such as fish over levels found in producers and primary consumers. Data are assessed in this report to determine which metals are bioamplified by the food chain. Levels of mercury in edible species are reviewed by this report and are compared to the enforcement level used by the federal Health Protection Branch (0.5 µg/g wet wt.). Information was gathered regarding the degree of metallic contamination of biota and sediments in the Fraser River study area and regarding the direction of future monitoring. Comparisons are made between levels of metals in Fraser River biota and biota of other waterways.

3.2 Sources of Metals

3.2.1 River Bed Scour

Based on estimates of loadings (Table 3-1 and 3-2), discharges to the river excluding those to the Banks, account for about 3.5 percent of the total copper, less than 1.0 percent of the total iron, and about 11.0 percent of the total zinc. Discharges to the study area, including those to the Banks (Iona Island STP and storm sewage) make up about

9.5 percent of the load of total copper, less than 1.0 percent of the total iron and about 13.0 percent of the total zinc. Most of the remaining load is associated with particulates and is likely derived from channel erosion upstream from Port Mann (Table 3-2; Tables 15 and 17 in Drinnan and Clark, 1980).

There are probably other minor sources of metals to the river. Comparatively high concentrations of lead in the sediments at the New Westminster Dock site (Chapman et al., 1980) (Section 3.3.2.2) suggest that docking facilities may be one minor source.

3.2.2 Landfill Leachates

Daily loadings of the metals cadmium, copper, nickel and lead, from leachates of landfills listed in Tables 3-1 and 3-3, did not appear high by comparison to other discharges (Table 3-1) or channel erosion (Table 3-2). The individual daily loadings of iron from the Richmond Landfill to the Main Arm at reach 8, the Braid Street Landfill the Port Mann Landfill, and the Leeder Landfill to the Mainstem at reach 2, were similar to those from the Lulu Island STP. Iron loadings from the Burns Bog Landfill were slightly lower. Loadings of zinc from the Burns Bog Landfill to Crescent Slough and the Richmond Landfill were higher than loadings from the other landfills, but fairly small by comparison to the other discharges (Table 3-1). Generally, contributions of metals by landfill leachates were less than the loadings from storm sewage (Table 3-1).

The impact of metals from landfill leachates on biota in the Fraser River has not been researched, but it is expected to be most significant in tributaries and drainage ditches.

3.2.3 Stormwater Discharges

Daily load estimates for storm sewer discharges were made by Ferguson and Hall (1979) and include additions due to tributaries in the study area.

The total metal contribution from stormwater was fairly large by comparison to the other discharges (Table 3-1), but was dispersed over a large number of outfalls (≥180). These were distributed from Barnston Island downstream to the Banks (Figure 6; Ferguson and Hall, 1979). An estimate indicated stormwater accounted for about 65 percent of the total iron and about 60 percent of the total lead and nickel entering the river in discharges. For copper and zinc the loadings estimated for stormwater were about 15 percent of the total discharged to the study area.

3.2.4 Industrial Discharges

Industrial effluents are discussed in detail by Swain (1980). Table 3-1 compares estimated metal loadings from this source to other discharges. It should be noted that metals data for industrial effluents may not be complete because sampling of all metals discharged may not be required by permit (Swain, 1980). Of those metals listed in Table 3-1, industry generally contributed less than 10 percent of the total load from dicharges, with the exception of zinc where industry accounted for about 50 percent of the load.

There were no data available for industrial loadings of metals to the Mainstem because there were no major industrial discharges contributing metals to the Mainstem in the study area (Figure 7; Swain, 1980). In the Main Arm, the Lafarge Canada Ltd. cement operation discharged about 6.0 kg/d iron, 0.4 kg/d lead and 0.2 kg/d zinc from the north side opposite Lions Island (Swain, 1980). This was a relatively small contribution compared to the Annacis Island or Lulu Island sewage treatment plants; the lead loading was greater than from landfill leachates, but the zinc was generally less. Titan Steel and Wire Co. Ltd. contributed 125 kg/d total iron and 0.4 kg/d each of total lead and total zinc to the Main Arm near Gunderson Slough (based on data from 1965 to 1977; Swain, 1980).

Western Canada Steel on Mitchell Island and Tree Island Steel Co. were the two major dischargers of metallic wastes to the North Arm. Western Canada Steel added 7.0 kg/d dissolved iron and 0.5 kg/d dissolved zinc to the river (based on data collected in 1975 to 1977; Swain, 1980). The metal finishing plant of Tree Island Steel Co. discharged process and cooling water containing daily loadings of 98 kg/d dissolved iron, 4.5 kg/d dissolved lead and 89 kg/d dissolved zinc (based on data from 1976 and 1977; Swain, 1980). The process water entered an exfiltration lagoon and the cooling water entered the river directly. The amount of lead discharged was similar to that discharged from the Annacis Island treatment plant and the amount of zinc was about twice that from the Annacis plant.

3.2.5 Sewage Treatment Plants

The sewage treatment plants (Iona, Lulu, Annacis, Ladner and Maple Ridge) discharged significantly more total copper (about 85 percent of the total, calculated from Table 3-1) than any other group of effluents. They accounted for about 30 percent of the total lead and 40 percent of the total nickel loading to the study area. Daily loadings in Table 3-1 were based on data from 1977, but data from 1970 to 1979 have been summarized by Cain and Swain (1980). The toxicity of each municipal effluent is discussed by Singleton (1980). Of the three large municipal plants (Iona, Lulu and Annacis), the Lulu Island effluent discharged the highest concentrations of copper, iron, zinc, nickel and manganese. The Iona Island STP effluent contributed the greatest loadings of cadmium, copper, lead and nickel per day compared to the Annacis Island and Lulu Island plants (Cain and Swain, 1980). The Annacis Island plant was a greater source of copper, iron, magnesium, manganese, nickel and zinc than the Lulu Island plant. Mercury was seldom detected in the plant effluents.

3.2.6 Summary of Effluent Sources

Of the single point sources of metals, the three large municipal plants (Iona, Lulu and Annacis) would be expected to generally have the greatest impact on the river. Stormwater contributed major loadings of iron and lead; but these are discharged from several outfalls (about 180). Usually industrial discharges (with the exception of zinc) and leachates from landfills accounted for small amounts of the total metal loading. This does not eliminate the possibility, however, that these discharges may be significant locally in any river reach to which they contribute.

3.3 Environmental Components Receiving Metals

All metals from the sources outlined in Section 3.2, enter the water component of the Fraser system. The chemical state of these metals is important because it has been shown that particular forms control the toxicity of metals to biota (Nielsen and Wium - Anderson, 1970; Pagenkopf et al., 1974). Drinnan and Clark (1980) have discussed the possibility of acute metal toxicity to biota in receiving waters. In general, for the main channels this possibility was thought to be low. The chemical form or species of metal present is also important to the process of biological accumulation. Contaminants may not be absorbed or retained by organisms if they are not present in "reactive" forms (Renfro et al., 1975; Giesy et al., 1977).

Metals in ionic form have a tendency to coagulate, or sorb to particulate matter. Most metals in rivers are biologically unavailable because they are present in inorganic complexes, in inactive coatings on particles, or within crystalline matrices

(Florence, 1977; Blutstein and Smith, 1978). Metals associated with particles ultimately settle out and enter the sediments where, depending on various conditions, they may become biologically available.

A brief summary of metals data for receiving waters is contained in Section 3.3.1. Section 3.3.2 presents selected sediment data relating to the Fraser River. Owing to the complexities associated with the dynamics of the bed sediments, suspended sediments and metal cycling phenomena, the treatment of the information is rather simplistic. McGreer and Vigers (1979) have discussed certain aspects of these topics relating to the Fraser River estuary. The section on sediments is intended to give background data for concentrations of metals in main channel and backwater sediments.

Data relating to levels of metals in various aquatic biota are summarized and presented in Section 3.3.3.

3.3.1 Receiving Waters

Data regarding trace metals in the receiving waters of the lower Fraser have been evaluated and are discussed in detail by Drinnan and Clark (1980). Physical features of the river, including flow and tidal effects, modify metal concentrations. Values of total copper, iron, lead, mercury, molybdenum, nickel and to some extent zinc are greater during freshet than at any other time of year because the metals are associated with suspended solids. Research regarding metal concentrations related to river flows and tidal cycling is continuing (Fletcher, K.W., UBC., Department Geological Sciences).

The metal data for receiving waters did not indicate many significant differences between or among reaches and the data rarely related well to effluent discharges (Drinnan and Clark, 1980). Concentrations of copper decreased toward the mouths of the river arms (from mean values of 0.05 mg/L to 0.02 μg/L in the Main Arm and 0.004 mg/L to 0.003 μg/L in the North Arm) where levels of suspended solids also decreased (Clark et al., in prep; Drinnan and Clark, 1980). The same trend was true for total iron (decreased from mean value of 2.1 mg/L to 0.5 mg/L in the Main Arm and 1.6 mg/L to 0.7 mg/L in the North Arm) (Drinnan and Clark, 1980). Conversely, zinc concentrations increased near the mouth. Levels of zinc and lead were higher in the North Arm than in the Main Arm and this was related to the greater industrial loadings to the North Arm and the lower flow rate (Drinnan and Clark, 1980). Data collected near the Annacis Island STP outfall indicated that occasional high copper values were probably related to the discharge (Drinnan and Clark, 1980). Mercury was not detected often in receiving waters, but when concentrations were measurable they periodically exceeded the level suggested for the protection of aquatic life (Drinnan and Clark, 1980). Most high mercury levels occurred in the North Arm and were detected in 1975 when untreated combined municipal sewage was discharged from New Westminster.

3.3.2 Sediments

The nature of the sediments in the study area of the Fraser River has been briefly described in Section 2.2.2.2 of this report where more detailed works on this topic are referred to. The fluvial sediments are of particular concern to the water quality of the Fraser River.

Sediments are often considered reservoirs or sinks for contaminants which have entered receiving waters, because the contaminants may accumulate in them. The sediments become important sources of metals for uptake by biota, either directly or after resuspension in the water column (Renfro, 1973; Cranston, 1976). Biological uptake of metals from sediments is controlled by the amount of exchange with the water column and the chemical phases of the metals in the sediments (Bindra and Hall, 1977). For example, the exchangeable and easily reducible phases of copper, which are less firmly bound to the sediments, are most easily accumulated by biota (Bindra and Hall, 1977).

In estuaries, metals such as iron, manganese and zinc sorb to oxide coatings of suspended particles to become part of the sediments as these particles settle (Grieve and Fletcher, 1977; Blutstein and Smith, 1978). Metals also bind or chelate to the polysaccharide components of bacteria (G. Geesey, personal communication). If sediments contain high concentrations of organics and large numbers of bacteria, the metal component may also be high. Many other factors control the metal content of the sediments including grain size and type of sediment, oxidation conditions and the presence of other metals (Cranston, 1976; Grieve and Fletcher, 1977; Bindra and Hall, 1977).

It is well known that particle size distributions of sediments in river channels are largely controlled by the velocity of the river. Sands drop out of suspension into the substrate from water of much faster velocity than smaller sized particles. Silt and clay may not drop out of suspension until the river velocity is considerably reduced (Culbertson, 1977). The profile of the river bed is responsible for fluctuations in river velocities above the substrate and subsequent variability in amounts of sand, silt and clay deposited in specific areas (Culbertson, 1977). In general, sediments of the main river channel of the Fraser River are expected to contain a greater portion of sand and larger sized particles than sediments bordering the river banks or of slower moving backwaters. Silt and clay particles are often covered with organic matter (Jonasson, 1977). Metals sorb easily to fine-grained substances having large surface areas including organic polymers, silt and clay (Forstner, 1977).

Concentrations of metals in sediments are expected to vary with the location of the site sampled in the river. The findings of a study in the lower Fraser on cross-sectional variability showed that the particle sizes of sediments varied across the river (Table 3-5; Figure 14) and that the sediments composed of more fine material usually had higher metal contents (Tables 3-6 and 3-7) (L.M. Churchland, personal communication). These principles will also apply to sediments of the Banks. Sediments of the main river channels, backwaters and banks will be discussed separately.

The factors discussed above, plus differing sampling and laboratory techniques (see Table 3-4) make comparisons of data from a variety of agencies difficult. Inconsistencies introduced to the results by differences in analytical techniques should be considered when reviewing the following discussion.

3.3.2.1 Sediments of the River Main Channels

The Environmental Protection Service (G. Packman, personal communication) sampled lower Fraser River sediment as part of a survey of dredge sites (Figure 14). The origin of these samples will be considered to be the main river channel. The data are limited and should be used with some caution yet contribute to the knowledge of the riverine sediments. The survey indicated that sediments of the North Arm may contain more fines (<0.075 mm) than the Main Arm, but less fines than the lower Mainstem near New Westminster and the bifurcation (Table 3-8). It has been suggested that because of changes in flow downstream from the canyon, fine material settles out in the river (Luternauer, 1974). The greater fine fraction in the North Arm compared to the Main Arm is believed due to its lower flow compared to the Main Arm (Luternauer, 1974). The data indicate that levels of organic carbon were higher in sediments of the North Arm than in the Main Arm, and similar or slightly higher than levels in the lower Mainstem (Table 3-9).

It appears that levels of acid extractable iron and manganese were higher in the lower Mainstem sediments than in sediments downstream in the river arms (Table 3-9). Levels of acid extractable zinc appeared to be least concentrated in the sediments of the Main Arm and most concentrated in those of the North Arm (Table 3-9). This result is consistent with zinc loadings (Table 3-1) and concentrations in receiving waters (Drinnan and Clark, 1980) The North Arm received the highest total loading of zinc compared to other regions of the river, with most of it originating from industries, including Tree Island Steel Co. (R 14) and Western Canada Steel (R 16). The landfills discharging the most zinc (Richmond Landfill and Burns Bog Landfill), were located on the lower Main Arm. Total zinc measured at several North Arm reaches was significantly higher than in the receiving waters of the Mainstem or Main Arm. Dissolved zinc was greatest in the North Arm (R 14 and R 17).

Levels of copper may have been slightly higher in the lower Mainstem and North Arm sediments than in the Main Arm (Table 3-9). These findings cannot be related to loadings to the river or to levels detected in the receiving waters. This result may be due to interacting conditions, such as generally smaller particle sizes in the lower Mainstem and North Arm, the influence of saline waters in the North Arm, or it may be an artefact due to a small data base.

Levels of acid extractable lead in the North Arm sediments were considerably higher than in the Mainstem or Main Arm. Loadings of lead to both the Main and North Arms were similar, but were much greater than those to the Mainstem (Table 3-1). Stormwater discharges carrying lead originating from automobile exhaust are most numerous to the North Arm. Boating and shipping traffic, another possible source of lead, is much heavier on the North Arm (F.R.E.S., Land Use and Transportation, 1978). Tree Island Steel Co. discharged lead to the upper portion of the North Arm (R 14), and lead was detected more frequently in the receiving waters of that reach (Drinnan and Clark, 1980). As with copper, the particle sizes of the sediments and other factors likely had an effect on lead content of the sediments.

Based on the limited data available, it appeared that the Annacis Island outfall had little measurable effect on the metal levels in the main channel sediments of the lower Main Arm surveyed in 1976. The possible exception was the concentration of nickel. The nickel level detected downstream from Annacis Island (R 8) was somewhat higher than the concentrations reported from other parts of the river (Table 3-9). Dissolved nickel was more frequently detected in the receiving waters of the lower Main Arm (R 11 and 12), but this was not related to the Annacis Island outfall (Drinnan and Clark, 1980).

Additional Main Arm sediment data collected by a number of agencies are summarized in Table 3-10. They generally compare with the main channel sediment data discussed above, shown in Table 3-9. However, levels of cobalt appeared to be higher. The mean value from Table 3-9 for the Main Arm was 10.8 µg/g and was 21.2 µg/g from Table 3-10. Also levels of zinc appeared to be lower based on the additional values in Table 3-10. A mean value of 44.2 µg/g may be calculated from Table 3-9 and 35.0 µg/g from Table 3-10, for sediments of the Main Arm.

3.3.2.2 Sediments of the River Backwaters

Levels of metals in sediments have been examined because sediments are potential sources of contaminants to biota. During such studies sediment samples are usually taken where the test organisms are most common, which in the case of macrobenthos in the Fraser, are shallow backwater areas.

Sampling backwaters probably tends to produce results which reflect the "worst case" of concentrations of metals available to biota. Refer to Figure 15 for location of these sites. The sediments from backwater locations had a much higher silt-clay component (<0.062 mm) than the main channel sediments and contained little coarse sand (Tables 3-8 and 3-11). Preliminary data showed that organic carbon was not detected at higher levels in sediments of the backwater areas of the Fraser compared with main channel sediments, with the exception of Ladner Side Channel (Tables 3-9 and 3-11). Concentrations of metals in sediments from backwater sites in the Mainstem were usually similar to those in main channel sediments, but high lead levels were observed at the New Westminster Dock site. Another extraction technique for sediments (non-residual), different from the one used for results shown in Table 3-12, also produced high concentrations of lead (mean value of 125 µg/g; Chapman et al., in prep.) at the New Westminster Dock site. Several metals were more concentrated in backwater sediments than in main channel sediments of the Main Arm. Copper was at times up to three times higher, iron up to twice as high, manganese up to twice as high and zinc up to three times more concentrated (compare Tables 3-9 and 3-12). In the North Arm, backwater sediments were slightly higher in manganese and zinc compared to the main channel sediments. Nickel was found at similar concentrations in both backwater and main channel sediments in the arms. It should be noted that the sediment data have been collected by various agencies and the laboratory techniques used for analyses differ and are listed in Table 3-4.

Levels of cadmium were fairly low in backwater sediments of the river; the highest concentration was detected in Ladner Reach (Table 3-12). The major effluent adding cadmium to the Main Arm was probably the Annacis Island treatment plant (F.R.E.S., Water Quality Summary Report, 1979), but it discharged less than one kg/d (Cain and Swain, 1980).

Levels of copper were higher in the sediments from the Ladner Side Channel than in sediments from other Fraser River sites (Bourque and Adams, 1975; Hall, 1979). The side channel is a protected backwater where the sediments were composed of 80 percent (mean value) silt and were comparatively high in organic carbon (7.5 percent) (Hall, 1979). Metals bind easily to this type of sediment. It is believed that marine waters, in conjunction with sediment characteristics, were responsible for the higher copper values in these sediments. In addition, the side channel receives runoff from the Cohilukthan Slough (Figure 15) which receives drainage from the surrounding agricultural land and the township of Ladner (Hall, 1979). Metals bind easily to suspended particles from humic soils (Forstner, 1977).

The copper levels in sediments of Ladner Side Channel were comparable to a mean copper level calculated for sediments from the Brunette Basin (56.0 mg/kg; Bindra and Hall, 1977). The headwaters of the Brunette receive industrial drainage and the entire basin receives storm water from local highways and residential areas (Hall et al., 1976).

Levels of copper in sediments from the other Fraser River sites, excluding Ladner Side Channel, were comparable (Table 3-12). Sediments from four other stations : north of the west tip of Barnston Island, downstream from Poplar Island, south of the western end of Mitchell Island and downstream from Annacis Island, also contained comparable levels of copper. The raw data for metal concentrations in sediments of these sites are shown in Appendix I, Table I-A. These data are summarized in Table 3-12.

The data base for cobalt from backwater sediments of the Fraser River is small and the values in Table 3-12 represent baseline concentrations.

Generally concentrations of iron in sediment samples from north of the west tip of Barnston Island, downstream from Poplar Island, south of the western end of Mitchell Island, downstream from Annacis Island and Ladner Reach were higher than levels in samples from the New Westminster Dock and Oak Street sites. This variability may be due to inherent characteristics of the samples, such as organic content or particle sizes, or may be due to variability in field and laboratory techniques. Levels of iron, particularly total values, in the receiving waters of the entire drainage including those upstream from Hope (Drinnan and Clark, 1980), suggested that iron is naturally a major component of the Fraser River and its sediments.

The iron loadings from storm sewers, landfill leachates, industry and treatment plants accounted for less than one percent of the total river load. The remainder originated from upstream sources according to calculations based on concentrations in receiving waters at Pattullo Bridge (Table 3-2). The relatively greater concentrations of iron detected in sediments of Ladner Side Channel and Williamson Slough may be related to the influence of salt water (Hall, 1979).

Levels of lead in sediments south of the western tip of Mitchell Island, in the North Arm, were somewhat higher than levels from the upstream site in the Mainstem (north of the west tip of Barnston Island) (Table 3-12). Industry, particularly Tree Island Steel Co. (R 14), contributed about 30 percent of the total lead discharged to the North Arm (Table 3-1). Levels of lead in sediments from the Oak Street site were similar to those from Mitchell Island. Although differences in levels found between the lower North Arm and Mainstem could be related to the particle size distribution and organic content of the sediments, both of the lower North Arm sites were downstream from Tree Island Steel Co. and Western Canada Steel and possibly influenced by their discharges. Another major source of lead to the North Arm is likely storm sewage, carrying lead emissions from automobiles. Storm sewers accounted for an estimated 70 percent of the total lead loading to the Arm (Table 3-1). Fuel from the many vessels using the North Arm is another possible source. The higher mean values of lead in sediments from New Westminster (Chapman et al., in prep.; Table 3-12), may be associated with the common presence of gasoline around the government dock where the samples were taken.

By comparison to the Fraser River, levels of lead were higher in sediments of the Brunette Basin (Table 3-10), where most of the lead contamination was attributed to storm sewage (Bindra and Hall, 1977).

Levels of manganese in sediments fluctuated along the river. Concentrations were higher downstream from the Annacis Island STP discharge. This discharge contributed about six times more total manganese per day to the river than the Lulu Island STP (Cain and Swain, 1980). The highest levels of manganese in sediments of the Fraser River were detected in the Main Arm downstream from Annacis Island (R 7) and in Ladner Side Channel (Table 3-12). The mean values for manganese from these two areas were higher than mean concentrations of manganese in sediments of Brunette Creek and Salmon River, which drains an agricultural area. There were no significant trends for manganese in the receiving waters, but it was detected in higher concentrations in the downstream reaches (Drinnan and Clark, 1980). Higher levels of manganese in receiving waters and sediments in the downstream portion of the estuary apparently were related to the marine influence (Hall, 1979).

Nickel followed a similar pattern to manganese in receiving waters and sediments.

Tree Island Steel Co. and Western Canada Steel contributed significant loadings of zinc to the North Arm (R 14 and R 16). As indicated this may influence the receiving water chemistry since total and dissolved zinc were significantly higher in reaches 14 and 17. The levels of zinc detected in the sediments of the North Arm (downstream from Poplar Island, Mitchell Island and Oak Street site) also may have been a result of the above industrial discharges. Another cause of high zinc levels in sediments at sites lower in the river, such as Oak Street, Ladner Side Channel and Williamson Slough, may be the retention of zinc in the brackish zone, as described by Grieve and Fletcher (1977).

Tables 3-9 and 3-12 list concentrations of mercury in sediments of the lower Fraser River. The data are for main channel and backwater sediments. Garrett et al. (1980) indicated that levels of mercury were fairly constant in the arms with the exception of sediments near Steveston (R 11). Data in Table 3-12 suggest that concentrations of mercury may have been somewhat higher in the Mainstem (Barnston Island site) and arms than shown by Garrett et al. (1980), but this may be related to the fact that all data in

Table 3-12 were from backwater sediments. The maximum concentrations of mercury in sediments at the New Westminster government dock (Chapman et al., in prep.) were the greatest detected to date in the river (about three times higher than at the other sites), upstream from the Banks (Table 3-12). The source of mercury to this site was not known. Since mercury levels in receiving waters were below detection limits it was impossible to locate and isolate upstream sources, using water chemistry data.

Levels of metals in sediments of other drainages are listed in Table 3-13. They may be compared to concentrations of metals in sediments from Fraser River backwaters because sediments taken from the other drainages likely had similar particle sizes. Levels of copper, iron, lead, manganese and zinc in sediments of the study area of the Fraser River were of the same order of magnitude as levels in sediments from the Columbia River, upstream from the smelter at Trail, B.C. These metals, plus mercury, were considerably lower in Fraser River sediments compared to sediments taken downstream from the smelter. Copper, lead and zinc were more concentrated in Fraser sediments than in sediments of Skeleton Creek, Oklahoma, a relatively undisturbed waterway (Namminga and Wilhm, 1977). Levels of cadmium, cobalt, copper, lead, and zinc were similar to, and at times higher than those from the Illinois River, a semi-industrial drainage in Illinois (Mathis and Cummings, 1973). Concentrations of cadmium, copper, lead and zinc in Fraser River sediments were similar to values in sediments from the Willamette River, Oregon, a river receiving effluents from base metal and mercury mining activities and other industry (Rickert et al., 1977). Zinc and mercury levels were occasionally higher in sediments of the Willamette River.

3.3.2.3 Sediments of the Banks

During the summer of 1975, sediment cores were analysed from both Roberts and Sturgeon Banks (Fletcher, 1976) (Figure 16). The cores taken from the upper portion of the sandflats of each bank, excluding the area of Sturgeon Bank influenced by the Iona Island outfall, were considered (Table 3-14). In general the levels of metals were similar in sediments from the two banks, but there appeared to be localized differences. For example, samples from Roberts Bank were occasionally lower in lead and zinc. The levels in sediments of the Banks were fairly similar to concentrations in sediments of the lower Fraser River.

The Iona Island STP outfall discharges a high loading of metals to the mudflats of Sturgeon Bank daily (Cain and Swain, 1980). This was reflected by the distribution of metals in the sediments of the Bank (Table 3-15). Levels of all metals measured (cadmium, cobalt, copper, iron, lead, manganese, nickel, zinc and mercury) were lowest north of the jetty, highest close to the outfall (up to 1 km west) and at intermediate levels in the sewage channel and south of the jetty further west from the outfall (from 1 km to about 3 km west) (B.C. Research 1973; 1975; 1977; and McGreer, 1981). These gradations in metal concentrations generally coincided with the impact zones indicated by the benthic biota (Figures 8a and 9). Suspended particulates in the effluent are high in organic carbon and have settled near the outfall and in the sewage channel. Metals bind easily to these particulates, in suspension or in the sediments, and this property probably accounts for the high metal concentrations in sediments (B.C. Research, 1975) and the relatively low toxicity of the sewage itself (McGreer, 1979a). B.C. Research (1977) reported that within the zone of serious impact near the outfall metal concentrations in sediments were lower in 1976 compared to 1974. The total area of sediment contamination, or the zone of influence, however, had expanded some 300 m westward over this time. Further expansion has been documented recently (McGreer, 1979a).

3.3.3 Biota

3.3.3.1 Algae

Algae are monitored for metal content to determine whether they have accumulated contaminants from the water column. A knowledge of levels of metals in primary producers is important to tracing transport through the food web.

Inland Waters Directorate undertook a program in 1977 to monitor levels of metals in periphyton of the Fraser (G.L. Ennis, personal communication). Algae were collected approximately monthly for a year from suspended plexiglass substrates at New Westminster, Marpole (near the Oak Street Bridge) and Steveston (Figure 17). The Fraser is very turbid and as a result samples also contained suspended particulates. Data from 1979 for sediment free algae (collected on substrates positioned to minimize sediment accumulations, followed by washing of the sample) showed that metal concentrations in these samples were much less than in samples containing sediment and collected at the same time (Table 3-16).

Figures 18 to 21 and Table 3-17 are based on information from algal samples with sediment. This information should be used cautiously owing to the probable overestimation in algal metal levels (Table 3-16 lists comparative values for samples with and without sediment from Marpole). Levels of copper, lead, nickel and zinc from other drainages are shown in Figures 18 to 21 for comparison and comparative data for a range of metals from other areas are given in Table 3-18. Despite overestimation of metals in algae from the Fraser River, the results are comparable to, or lower than levels reported in several publications. Results indicate that the Fraser levels fell between those of a pristine and polluted situation. Copper, lead, manganese and zinc were more concentrated in periphyton from Still Creek than in samples from the Fraser River. Copper, manganese, nickel and zinc in Fraser River periphyton were greater than those associated with oligotrophic snowshed conditions (Fjeringstad, 1973), but copper, lead, nickel and zinc were less than those from waters in an area of mining activity (Trollope and Evans, 1976).

A comparison of metal concentrations in periphyton among the three Fraser River sites shows that ranges of metal concentrations often overlapped (G.L. Ennis, unpublished data; Figures 18-21; Table 3-17). Lead and zinc appeared to be higher in algae from the Mainstem (New Westminster) and in algae from the North Arm (Marpole) compared to algae from the Main Arm (Steveston). This is consistent with the water chemistry results in Drinnan and Clark (1980) for the receiving waters of the North Arm. Total and dissolved zinc were higher in the receiving waters of the North Arm (R 17), probably due to the high loadings from industrial discharges and the effects of brackish water on zinc. Mercury appeared to be highly concentrated in some algal samples, particularly from New Westminster (G.L. Ennis, unpublished data). Levels of this metal in periphyton require further investigation.

Species abundance varied in the periphyton at each site (G.L. Ennis, unpublished data). Species differences in conjunction with the ability of certain algae to selectively concentrate particular metals, may have contributed to the differences in metal levels detected at each site (Trollope and Evans, 1976; Cushing and Rancitelli, 1972). Accumulation of metals by Fraser River algae likely occurs since levels in sediment free samples were several times higher than in receiving waters.

Table 3-17 also shows levels of metals in attached algae from the Iona Island jetty (B.C. Research, 1975). The concentrations of all metals (Cd, Co, Cu, Fe, Pb, Mn and Zn) except nickel, were higher in rockweed (Fucus gardneri) collected from the south side of the jetty, along the sewage channel, than in specimens from the north side. This indicates that there was some accumulation of metals from the discharge.

Levels of cadmium, copper, iron, lead and manganese in Fucus on the north side of the jetty are comparable to levels in algae from Menai Straits, Wales. The Straits do not adjoin any significant anthropogenic sources of contamination (Foster, 1976). Fucus serratus sampled in the Severn Estuary, England which receives much industrial waste had higher concentrations of cadmium and zinc than Fucus from the south side of the Iona jetty (Tables 3-17 and 3-18).

3.3.3.2 Invertebrates

(a) Amphipods

Anisogammarus confervicolus is preyed upon commonly by juvenile salmon in the lower Fraser (Goodman, 1975; F.R.E.S. Habitat Report, 1978). It has been ranked as fifth or sixth in dietary importance to chum, pink, chinook and sockeye fry in the Ladner area (Levy et al., 1979). These amphipods feed on algae, including Enteromorpha and diatoms, and on detritus (Levings, 1976). Bacteria associated with the detritus probably also provide some nutrition. In addition to diet, the water column and sediments are likely sources of metal contamination.

Few amphipod samples have been taken from the Fraser River for metals analysis. The Inland Waters Directorate sampled Anisogammarus confervicolus from Oak Street and A. confervicolus and Corophium spp. from Westham Island (Chapman et al., in prep.) and the Water Investigations Branch sampled A. confervicolus in Ladner Reach. Samples contained from several to hundreds of specimens. The data were distinctly variable (Table 3-19). Although different extraction procedures (Table 3-20) were used on samples by the two agencies, it was expected that concentrations of metals in A. confervicolus from Westham Island would be fairly similar to concentrations in samples from Ladner Reach. Levels of iron, manganese, nickel and zinc in the Ladner Reach sample were much higher than in the Westham Island sample, and copper and lead were somewhat higher. The data from the Ladner Reach sample are inconsistent with water quality data, which did not suggest that levels of iron, manganese nickel or zinc were significantly higher in the lower Main Arm than elsewhere in the river, and with the exception of iron, the results are inconsistent with sediment data. The amphipods sampled were trapped from a dock in the reach. Further sampling should be done to determine whether the sample was contaminated during the collection procedure or whether the data are valid.

The sources of metals to amphipods have yet to be verified, but recent work with Anisogammarus confervicolus implicated food as an important source (Bindra and Hall, 1978).

(b) Oligochaetes and Chironomids

Oligochaetes are one of the dominant macroinvertebrates in fine sediments of the lower Fraser River. Chironomid larvae are also common in this habitat. Oligochaetes ingest sediment, but actually feed on bacteria associated with the organic component (Brinkhurst and Jamieson, 1971). Most chironomids taken from the lower portion of the Fraser River are Chironominae and may feed on oligochaetes, leeches, dipteran larvae and other invertebrates, algae and detritus (Bryce and Hobart, 1972; Loden, 1974).

It is assumed (Patrick and Loutit, 1976; Chapman et al., 1980) that oligochaetes acquire most metal contamination from the bacteria and sediments that they ingest. The bacteria may be a significant source (Patrick and Loutit, 1976; 1978); their polysaccharide components are suspected to be enriched with metals in contaminated habitats (G. Geesey, personal communication). Chironomid larvae likely accumulate significant amounts of metals from sediments and their food, although the overlying waters, and interstitial waters particularly, cannot be ruled out as potential pools of metal contamination. Oligochaetes may be consumed by bottom feeding fish and to a lesser extent by salmonids (Milbrink, 1973; Anderson et al., 1980). Chironomid larvae may be taken by salmonids, as well as sculpins, sticklebacks, flounders and other coarse fish (Kaczynski et al., 1973; Mason, 1974; Scott and Crossman, 1973; Levy et al., 1979). Of food items identified from salmon fry guts, chironomid larvae ranked either second or third in importance for chinook, sockeye, pink and chum from the lower Main Arm (Levy et al., 1979).

The Water Investigations Branch monitored oligochaetes north of the western tip of Barnston Island, downstream from Poplar Island, south of the western tip of Mitchell Island and downstream from Annacis Island (Figure 17). Collections were made twice in 1978, in the winter (prefreshet) and late summer (postfreshet). Appendix I outlines the purpose for the study and describes the sampling locations, field methods used and sample treatment prior to analyses by the Environmental Laboratory. Table I-B of Appendix I shows the complete data for benthic biota which are summarized in Tables 3-21 and 3-25. It was necessary at times to include chironomid larvae in these samples (Appendix I, Table I-B) to meet the biomass requirements of the Environmental Laboratory (see Table 3-20). The Inland Waters Directorate sampled oligochaetes monthly throughout 1978, from the New Westminster Dock site and the Oak Street site (Chapman et al., 1980). Results are shown in Table 3-22. In 1977, the Westwater Research Centre took oligochaete samples from three sites in Ladner Side Channel. The resultant data are also shown in Table 3-22.

The extraction methods used for metals analyses by each agency are listed in Table 3-20. Differences in technical procedures may account for some of the variability in the results. Also, differences in species distributions at the various sites may add to this variability. Tables 2-8 and 3-23 show the distribution of species in the river and the dominant forms taken at each site.

Bioconcentration factors, the ratios of metal concentration in benthic organisms to the metal concentration in sediment, were determined using mean values for organisms and mean values for sediments. Bindra and Hall (1977) concluded that when this value exceeds 1.0 the contaminant has been bioconcentrated. Sediments generally contain the highest concentrations of metals compared to the other environmental components of the Fraser system. They may be the most important source of contamination to the benthos.

The few analyses conducted for arsenic showed that it was detectable in the benthos (range of 4.0-32.0 µg/g dry weight; Table 3-21). Levels of cadmium appeared to be low in all oligochaete samples (<1.0-5.1 µg/g dry wt.). Copper levels showed some variability. The bioconcentration factor for copper at the Barnston Island site was above 1.0 (Table 3-25) indicating that copper was higher in the benthos than in the sediments.

Samples from this site contained chironomid larvae and these larvae alone bioconcentrated copper at the New Westminster Dock and Oak Street sites (Table 3-24). The bioconcentration factors for copper in oligochaetes from the New Westminster site and downstream from Annacis Island approached 1.0 (Tables 3-22 and 3-25).

Ideally, the same extraction procedure used for analysing biota should be used for sediments. However, Bindra and Hall (1977) used a harsher extraction technique (perchloric) for sediments, than for biota (Tables 3-4 and 3-20) which will likely have the effect of moderating bioconcentration factors (M.J.R. Clark, personal communication).

Mean concentrations of iron in oligochaetes from all sites were fairly consistent (range of 2 500 to 4 855 µg/g dry weight) and well below levels detected in the sediments. Lead was more concentrated in oligochaetes from New Westminster than from the other sites (mean value of 39.0 µg/g dry weight), but levels in the sediments there were also high resulting in a concentration factor less than 1.0 (Table 3-22). Levels of some metals although not bioconcentrated by oligochaetes may still be elevated, reflecting levels in sediments.

Concentrations of manganese in all oligochaete samples were similar as were those of nickel. The highest concentration of manganese was found in a sample from the Barnston Island site (291 µg/g) and the highest nickel concentrations were detected in samples from the Barnston Island site and the New Westminster Dock site (13.0 µg/g) (Tales 3-21 and 3-22). Neither metal was bioconcentrated (Tables 3-22 and 3-25).

Mean concentrations of zinc were fairly high in oligochaetes from all sites except Oak Street and Ladner Side Channel (Tables 3-22 and 3-25). Samples from Barnston Island (R 1), downstream from Poplar Island (R 14) and downstream from Annacis Island all showed concentrations of zinc above levels occurring in the sediments (Table 3-25). The concentration factors for zinc at the Mitchell Island and Oak Street sites were close to 1.0 (Table 3-22).

According to available data, mercury was more concentrated in all oligochaete samples than in the sediments. The bioconcentration factors ranged from about two at the Oak Street site to ten downstream from Annacis Island (Tables 3-22 and 3-25).

The metal mercury and occasionally the metals zinc and copper were bioconcentrated by oligochaetes.

Unlike tubificids, chironomid larvae do not ingest sediments nor do they spend their entire life cycle living in them. Nonetheless they are closely associated with the sediments, and bioconcentration factors, comparing metal levels in chironomids to levels in the sediments are considered (Namminga and Wilhm, 1977).

Samples of chironomid larvae were collected from three sites, New Westminster, Oak Street and Ladner Side Channel. The data base is small and the results are variable (Table 3-24). Cadmium was often below detection limits in samples from the New Westminster Dock or Oak Street sites. It was detected and bioconcentrated in specimens from Ladner Side Channel. There were problems with detection limits for cobalt, lead and nickel in chironomid samples. Manganese was detected (range of 6.2 to 103 µg/g dry weight), but not bioconcentrated.

Iron was more concentrated in chironomid samples from the Oak Street site (5 000 µg/g) compared to the New Westminster Dock site (2 040 µg/g), but was not bioconcentrated (Table 3-24). Species of chironomid larvae from the lower North Arm contained much haemoglobin (of which the metal component is iron), which may have accounted for the apparent increase in iron content of the organisms at the Oak Street site. Copper and zinc were always detectable, and were higher in the larvae than in the sediments with the exception of copper in Ladner Side Channel and zinc at the New Westminster site. Mercury was bioconcentrated by chironomids at the Oak Street site; there are no data from the New Westminster Dock site or Ladner Side Channel.

Like oligochaetes, it appears that chironomid larvae cannot efficiently eliminate copper, zinc or mercury (Namminga and Wilhm, 1977). It has been suggested that zinc is adsorbed by the chironomid cuticle (Namminga and Wilhm, 1977). This is a physically external method of accumulation over which organisms may have no physiological control.

Comparative figures for metal contamination in benthos of other systems are given in Table 3-26. Oligochaetes from the Brunette system contained much higher levels of copper, iron, lead, manganese and zinc than those from the Fraser River. Concentrations of copper and lead in oligochaetes from the Salmon Basin were similar but, the Salmon Basin specimens were higher in iron, manganese and zinc. Levels in Fraser River oligochaetes were close to those detected in oligochaetes of the Illinois River, Illinois, which receives industrial, domestic and storm sewer discharges. Concentrations of zinc appeared to be lower in oligochaetes from the Illinois River compared to the Fraser, but that river, where sampled, is not influenced by salt water as is the lower Fraser River.

Levels of copper, iron, lead and manganese were slightly higher in chironomid larvae from the Fraser than in those from the Salmon River Basin (Figure 3) and concentrations of zinc in chironomid larvae from both drainages appeared to be similar (Tables 3-24 and 3-26). All metal concentrations in the larvae were higher than in specimens from an unaltered system, Skeleton Creek, Oklahoma. Levels of cadmium, lead and zinc were considerably higher in immature insects, 10 km downstream from a lead-zinc smelter on the Columbia River at Trail, B.C.

Concentrations of metals in benthic invertebrates from the lower Fraser River were higher than in organisms from a pristine drainage, similar to levels in benthos from another semi-industrial river and less concentrated than in organisms from a system influenced by a smelter.

(c) Bivalves

Bivalves sampled from the Banks can be divided into two groups: those attached to the jetties and those which occupy the sediments. The group on the jetties is primarily associated with the water column from which it filters food, and the group from the sediments filters the overlying water for food or feeds on "deposits" (organic matter and bacteria) from the surrounding sediments. In the first case sources of metal contamination include the overlying waters, suspended sediment, plankton, organic debris and associated bacteria. Sediments are an additional direct source of metal contamination to the second group.

Levels of metals in oysters collected from the Iona Island Jetty generally showed little variation with collection location. However, concentrations of iron and lead were higher in oysters collected from the south side of the jetty, compared to the north side (Table 3-27. The south side is affected more frequently by the treatment plant discharge. Levels of copper and iron were higher in specimens collected from the Iona Island Jetty than in oysters collected from the open Oregon coast (Table 3-28). Levels of manganese and zinc were comparable. Oysters appear to retain high concentrations of zinc even in areas not directly affected by discharges. This is likely due to the physiology related to shell construction (Huggett et al., 1975), and makes comment on these apparently high values difficult (Windom and Smith, 1972). Nelson and Goyette (1976) found extremely high zinc values (8 000-17 000 μg/g dry wt.) in oysters close to pulpmill outfalls discharging zinc and lesser levels (2 000-5 000 μg/g dry wt.) in oysters not directly affected by the discharges. Zinc levels in oysters from the Iona Island Jetty were similar to levels in specimens not directly affected by pulpmill discharges. Levels of cadmium, copper and zinc were higher in oysters collected from waters receiving industrial and urban discharges in Tasmania, Australia (Table 3-28), than in oysters collected from the Iona Island Jetty.

Table 3-27 also lists concentrations of metals found in bottom dwelling bivalves from both Sturgeon and Roberts Banks. The first survey of metal levels in clams from the Banks did not sample specimens south of the Iona Island Jetty or in an area influenced by the sewage treatment plant outfall. Levels of most metals were comparable with a number of other areas with the exception of silver and copper which were generally higher on Sturgeon Bank than in other areas on the Pacific Coast (Table 3-28).

In 1976 the Environmental Protection Service monitored metal concentrations in soft tissues of burrowing bivalves from the sediments of both Sturgeon Bank (29 Stations, Figure 22) and Roberts Bank (7 Stations, Figure 22) in more detail, (D. DeMill, unpublished data). Macoma balthica were collected from all stations when possible, and Cryptomya californica, Mya arenaria and Clinocardium nutalli were also monitored when present. Table 3-29 is a summary of pooled data for M. balthica, C. californica and M. arenaria, excluding levels for mercury. The stations have been combined into four groups: those north of the Iona jetty (A); those south of the jetty in the zone of influence of the Iona Island STP effluent (B); those from south Sturgeon Bank (C) and those from Roberts Bank (D). Numerical techniques were not applied to the data, but it appears that cadmium, copper and to a lesser extent lead, were more concentrated in specimens from an area affected by the Iona Island outfall than in specimens from other areas. Values for arsenic ranged from less than 0.81 to about 2.0 μg/g wet weight, for copper from 14.0 to 136 μg/g dry weight, for lead from 3.19 to 7.56 μg/g dry weight and for zinc from 95.0 to 422 μg/g dry weight (D. DeMill, unpublished data).

A summary of mercury concentrations in M. balthica, from both Sturgeon and Roberts Banks, is shown in Table 3-31. An analysis of variance indicated that there were significant differences in mercury concentrations among all stations monitored on the Banks. There were no significant differences in levels of mercury among specimens taken north of the Iona jetty, south of the jetty and on Roberts Bank. The mean levels of mercury in M. balthica were higher at stations 3, 14, 20, 22 and 25 of Sturgeon Bank and station 33 of Roberts Bank, compared to the others (Figure 22; Table 3-31). These stations were grouped together using the Newman-Keuls ranking system (Table 3-31). Specimens from stations 3 (near the south west tip of the North Arm Jetty), 25 (at a midwest point on Sturgeon Bank) and 30 (northwest on Roberts Bank) had the highest individual concentrations of mercury compared to concentrations in specimens from the other sites, but the enforcement level for edible tissues of 0.5 µg/g wet weight (Table 3-30) was not exceeded in these samples.

Other investigators (Bindra and Hall, 1977; McGreer 1979 a and b; McGreer and Vigers, 1979) have studied metal contamination in M. balthica in the zone influenced by the Iona Island STP effluent (Figure 23). Table 3-32 summarizes this information. As indicated in Table 3-20, different lab techniques were used by various agencies, which may have introduced variability to the data. However, some trends were apparent. The additional data support the findings that copper and mercury were more concentrated in M. balthica near the outfall and in the sewage channel than in specimens from sites further west from the outfall and south of the sewage channel. McGreer (1979a) found that concentrations of mercury exceeded the enforcement level for edible tissues in specimens in a zone extending less than 1.0 km from the outfall. McGreer and Vigers (1979) found that higher concentrations of mercury were detected more frequently in that same area near the Iona outfall, as compared to Roberts Bank, but that the maximum concentration was 0.36 µg/g wet weight. Concentrations were higher in October than in August. This seasonal trend was also true for arsenic, cadmium and copper.

McGreer (1979 a and b) found that copper, zinc and mercury were bioconcentrated by M. balthica, above levels in the sediments. These clams were absent from an area immediately adjacent to the Iona Island STP outfall (Figure 24), and this abiotic area appears to be increasing as a result of continued metal contamination (McGreer, 1979b). Copper may be an important comtaminant in this regard as indicated by its distribution in sediments (Figure 24a). It has been suggested that larvae of M. balthica cannot settle near the outfall due to the interference from metal levels in sediments. The contamination might inhibit settlement of M. balthica larvae, or cause the larvae to avoid the sediments (McGreer, 1979a).

Bioassays using adult M. balthica conducted with the effluent from the Iona Island STP, produced no mortalities of clams exposed to non-chlorinated, chlorinated, or chlorinated-dechlorinated effluent (McGreer, 1979a). Sublethal tests showed that burrowing and avoidance behaviour of adult clams was affected (McGreer, 1979b). Fisheries and Oceans caged M. balthica, and suspended them in the Iona Island sewage channel. From 37 up to 100 percent mortality of the clams was observed (Fisheries and Oceans, unpublished data).

(d) Crabs

Cancer magister, Dungeness crabs, are taken commercially from the Banks of the Fraser River estuary and supply about 40 percent of the total British Columbian catch (F.R.E.S., Habitat Report, 1978). Some data have been collected regarding metal levels in these crabs (Bawden et al., 1973; McGreer and Vigers, 1979; Figure 23; Table 3-33). Mobility and variation in age complicate assessment of the information. Older, larger crabs contain higher concentrations of certain metals (Bawden et al., 1973). Many components of the environment are potential sources of contamination. Their feeding habits are diverse and change with age, further complicating the investigation of these sources.

Data from 1973 showed that concentrations of most metals in crabs from the Banks were similar to levels in crabs from Cowichan Bay or Kitimat Arm (Bawden et al., 1973; Tables 3-33 and 3-34). Copper and mercury were exceptions and levels of these metals were higher in specimens from the Banks compared to those from the other two areas. Levels of copper in crabs from the two Banks were comparable (Sturgeon Bank: 38-150 μg/g; Roberts Bank: 51-68 μg/g). More recent data (McGreer and Vigers, 1979) generally supported these findings (Table 3-33), but suggested that there were variations in metal levels with season. In August mean concentrations of copper were comparatively higher in crabs from Roberts Bank, but arsenic and zinc levels were higher in specimens from Sturgeon Bank as compared to Roberts Bank. In October concentrations of copper, arsenic and zinc were similar in crabs from both areas. Although median values are reported for copper concentrations in specimens collected in California from waters receiving either a large combined municipal discharge or no direct discharge, levels of copper in crabs from Sturgeon and Roberts Banks seem similar to these (Table 3-34).

Mercury was more concentrated in *C. magister* from Sturgeon Bank (mean value 0.34 µg/g) than in specimens from Roberts Bank (mean value 0.08 µg/g) in 1973 (Bawden *et al.*, 1973). The Food and Drug Directorate enforcement level of 0.5 µg/g wet weight for edible tissue was exceeded in three specimens of 12 sampled. The Iona Island STP outfall was implicated as the source of mercury contamination (Bawden *et al.*, 1973), but it may represent only one of many sources of mercury to the Banks. McGreer and Vigers (1979) found that concentrations of mercury were higher in crabs from Sturgeon Bank than from Roberts Bank during August. In October the mercury levels in specimens from both Banks were similar and maximum concentrations of 0.37 µg/g wet weight mercury were detected at each location. Because these upper range concentrations for mercury approach the Food and Drug Directorate enforcement level of 0.5 µg/g wet weight, McGreer and Vigers (1979) suggested that further investigation into these levels is required.

The mean concentration of the metalloid arsenic was higher in Sturgeon Bank crabs (6.7 µg/g) compared to Roberts Bank specimens (5.2 µg/g). The concentrations were generally comparable to levels found in *C. magister* from the northwest coast of Vancouver Island (LeBlanc and Jackson, 1973) (Table 3-34). Although comparing different species may be of questionable value, these levels are lower than those reported in crustaceans from the Thames Estuary in 1926 (Penrose, 1974), higher than levels found in shrimp listed as U.S. commercial data (Penrose, 1974), and lower than levels found in prawns off the coast of West Greenland (Bohn, 1975). Arsenic levels are known to be higher in marine waters than in fresh water and are often relatively high in marine crustaceans (NRCC, 1978). It has been shown that in some crustaceans, such as shrimp, arsenic is present in a chemical form not readily assimilated by other animals or man (Zook *et al.*, 1976).

3.3.3.3 Fish

(a) Specimens From The River

The levels of metals in fish from the Fraser River not only give some indication of whether bioconcentration has taken place through the food web, but also yield valuable information on a system supporting many edible species. There are three sources of contaminants to fish : the water column, their food and the sediments (California Coastal Water Research Project, 1976; 1977). Certain species in the Fraser

River live mainly in the water column and others on or associated with the bottom; some are resident species and others migratory or non-resident. These variables affect the importance of sources and type of contamination to each species.

In 1973, fish were surveyed by the Westwater Research Centre and the following information has been taken from a report documenting the study (Northcote, Johnston and Tsumura, 1975). Specimens were collected at 14 sites from Hope downstream (see Figure 3 for sites 1-9; sites 10 to 14 extended from Mission upstream to about 15 km downstream of Hope) and analyses were carried out on 350 specimens representing 14 species of fish. Most metals, including silver, cobalt, molybdenum, nickel, cadmium and lead, were either not detectable or present in low concentrations in this survey.

Cadmium was detected once (0.38 μg/g wet weight), in a white sturgeon from the North Arm. Lead was detected in four fish, two from the North Arm and two from the Mainstem, but all levels were below 1.0 μg/g (wet weight). Copper, iron, mercury, manganese and zinc were much more ubiquitous and were present in almost all fish sampled.

Levels of iron and manganese did not appear to be of concern and were not species dependent. Copper was more concentrated in mountain whitefish, cutthroat trout, rainbow trout, peamouth chub and sockeye salmon compared to the nine other species analysed. Zinc concentrations were species dependent and were highest in northern squawfish, peamouth chub, and prickly sculpin. Concentrations of zinc apparently decreased with increasing fish size (Northcote, Johnston and Tsumura, 1975). Northcote, Johnston and Tsumura (1975) indicated that levels of copper and zinc in fish muscle from the Fraser River were well below the regulation levels for edible aquatic animal products in use at that time (Table 3-30).

Mercury has been implicated as a metal of concern (Northcote, Johnston and Tsumura, 1975). Levels in salmonids were found to be low, but northern squawfish and prickly sculpin had average concentrations of over 0.65 μg/g wet weight. Although these species are not usually considered edible fish, concentrations in them exceeded the Canadian Food and Drug enforcement level of 0.5 μg/g wet weight for edible tissues. Levels in white sturgeon, largescale sucker and peamouth chub also at times exceeded 0.5 μg/g wet weight and were generally above 0.2 μg/g, the maximum level normally expected to be "natural background" (Zitko et al., 1971). Higher "background" levels are anticipated in regions of high mercury mineralization (Northcote, Johnston and Tsumura, 1975). The concentrations of mercury generally increased with fish size. This is a well documented relationship particularly for carnivorous fish (Manasveta and Siriyong, 1977).

In 1978, 207 additional fish specimens from the 1973 collection, which had been frozen and stored, were analysed (Drinnan and Northcote, in prep.). There were four new species added to the original list of 14 (bridgelip sucker, redside shiner, black crappie and burbot) and the data for Dolly Varden, cutthroat trout, largescale sucker, peamouth chub and prickly sculpin were increased considerably. There were no differences between copper or zinc concentrations from 1973 and 1978 analyses and these data were combined. Mercury was slightly lower in the 1978 analyses, possibly due to loss of the more volatile organic components during storage. For the species peamouth chub, northern squawfish and largescale sucker, there was no difference statistically in mercury levels between the two groups of analyses and therefore it was determined that the two groups of data could be combined (Drinnan and Northcote, in prep.). Data for the most ubiquitous metals are shown in Table 3-35 and Figure 25.

Cadmium, lead and nickel were not detectable in these additional samples (Drinnan and Northcote, in prep.). Chromium and arsenic were measured in 1978. Chromium was detected in six species (carp, peamouth chub, squawfish, largescale sucker, cutthroat trout, Dolly Varden) a total of 10 times, but it never exceeded 0.5 µg/g wet weight. Arsenic determinations were carried out on 21 fish, selected because concentrations of other metals were elevated in the epaxial muscle. Arsenic concentrations were all below detection limits. Copper and zinc data were similar to those of the initial survey and likely not of concern (Drinnan and Northcote, in prep.).

The mean mercury level exceeded 0.5 µg/g wet weight again in northern squawfish and prickly sculpin. Also concentrations in nine of 51 white sturgeon, 22 of 116 largescale sucker and 13 of 125 peamouth chub, exceeded the enforcement level for edible tissues of 0.5 µg/g wet weight. By comparison mean mercury concentrations in Dolly Varden, rainbow and cutthroat trout, which are not considered groundfish, were about three times less than mean values found in northern squawfish, prickly sculpin, largescale sucker and peamouth chub. High mercury values were found in various species of fish from all 14 sites from Hope downstream to the river mouth.

An analysis of variance carried out on pooled metal data (1973 and 1978 analyses) from fish of the North Arm, Main Arm, lower Mainstem, middle Mainstem and upper Mainstem showed that there were no regional trends for copper or mercury (Drinnan and Northcote, in prep.; Figures 26 and 27). That is, mean concentrations of copper and mercury in any species were similar in the five regions. Analysis of variance of the zinc data suggested that concentrations in fish from the North Arm were significantly higher than in specimens from the other regions (Drinnan and Northcote, in prep.; Figure 28). This is consistent with the water chemistry data (Drinnan and Clark, 1980) and the fact that oligochaetes from the North Arm near Poplar Island and chironomid larvae from Oak Street bioconcentrated zinc above levels in the sediments.

Levels of metals were measured in ammocoete larvae collected in 1978 (I.W.D., unpublished data; W.I.B., unpublished data) from Barnston Island (north of its western tip), downstream from Poplar Island, downstream from Annacis Island, at New Westminster Dock site and at the Oak Street Bridge site (Table 3-36). These organisms can live in the substrate for up to six years filtering water for organic food matter (Northcote, 1974). They normally filter suspended material from the water directly above the substrate, but at times may filter interstitial waters containing some sediments (Moore and Mallatt, 1980).

Metal levels in ammocoetes were compared to levels in the sediments from which they were taken. Mercury was consistently concentrated to at least 10 times the levels found in the sediments (Table 3-36). Zinc also was concentrated over levels detected in the sediments at most sites, but not at all sampling occasions at the New Westminster Dock site. Levels of copper were similar in ammocoetes and sediments at the Barnston Island site and downstream from Annacis Island where the bioconcentration factors neared one (Table 3-36).

Little can be said relating water chemistry and metal concentrations in ammocoetes or regarding regional trends because there are insufficient data.

Comparisons between metal concentrations in fishes from the Fraser River and fishes of other watersheds must be made cautiously. Levels of metals vary greatly between species, within species from a single location, and with size, sex and sexual maturity. Table 3-37 lists some comparative data for other areas in British Columbia and some of the same species found in the Fraser River. Data were not readily available for many B.C. watersheds and for most species found in the Fraser River. For those listed, the sample sizes are much smaller than for the Fraser River fish and few metals were monitored. Assuming epaxial muscle of fish is usually about 80 percent moisture (based on data from the Enviromental Laboratory), some comparisons can be made after transforming Fraser River data to estimated dry weights, by multiplying wet weight by five.

There were some differences in concentrations of copper between Fraser River rainbow trout, Dolly Varden and largescale sucker, and those fish from other British Columbia watersheds, excluding Buttle Lake. Levels in cutthroat trout, mountain whitefish and peamouth chub from the Fraser River may have been higher than in the other areas, particularly in the upper range of values. Similarly, the upper range concentrations of zinc in rainbow trout, cutthroat trout, Dolly Varden, mountain whitefish and largescale sucker from the Fraser River were higher than in fish from other locations. Levels of mercury in rainbow trout, cutthroat trout, mountain whitefish and Dolly Varden were comparable to those given in Table 3-37, but the upper range concentrations were higher especially in largescale sucker and peamouth chub from the Fraser River compared to other systems. The upper range for mercury in largescale sucker taken from the Fraser Canyon and from downstream of Hope were similar (Tables 3-35 and 3-37).

The significance of each part of the aquatic habitat to contaminant accumulation by fish depends on their natural history. Some species (e.g., salmonids) are often associated with the water column while others are often associated with the bottom (e.g. largescale suckers, peamouth chub and sculpins). Salmonids would be expected to accumulate less contamination from the sediments than would bottom fish. Although levels of metals were 10 to 1000 times more concentrated in Fraser River fish than in the receiving waters, it is expected that metals can diffuse across gill epithelia (Northcote, Johnston and Tsumura, 1975) and the thin membranes inside the mouth (Gregory, 1979). It has been suggested that another major route for metal accumulation is through the gut during digestion of food (Rucker and Amend, 1969; Patrick and Loutit, 1978).

Mercury was detected in some fish at levels higher than in invertebrates, suggesting it is concentrated through the food chain. Higher levels of mercury were detected in bottom feeders (largescale sucker, peamouth chub and prickly sculpin) and piscivorous fish (white sturgeon and northern squawfish).

(b) Specimens From The Banks

McGreer and Vigers (1979) collected information on concentrations of metals in juvenile starry flounders and juvenile chinook salmon from Sturgeon and Roberts Banks (Figure 23). Two sites for collection were chosen on Sturgeon Bank, one about 1 000 m west of the Iona Island STP outfall and approximately 200 m south of the sewage channel, the other about four km west of the outfall and the same distance south of the channel. The enforcement level for edible tissues for mercury (0.5 µg/g wet weight) was not exceeded in any of the specimens analysed (Table 3-38). The data for starry flounders suggested that the overall mean concentration for mercury was higher in specimens from the Sturgeon Bank site, four km west from the outfall, than in specimens from the Sturgeon Bank site 1.5 km West of the outfall or from the southwest portion of Roberts Bank, north of the Westshore Terminal (Figure 23). The maximum value for mercury detected in flounders (0.44 µg/g wet weight) was measured in a specimen from the westernmost site of Sturgeon Bank (McGreer and Vigers, 1979).

Levels of arsenic did not appear different among the three sites, but the maximum value (3.57 µg/g wet weight) was again detected at the westernmost site of Sturgeon Bank. Concentrations of copper and zinc were comparable in specimens from both banks. Mean values of copper ranged from 0.24 to 0.78 µg/g wet weight from Sturgeon Bank and 0.25 to 0.82 µg/g wet weight from Roberts Bank. Mean concentrations of zinc ranged from 5.0 to 8.5 µg/g wet weight from Sturgeon Bank and from 6.1 to 9.0 µg/g wet weight from Roberts Bank.

Levels of certain metals in juvenile starry flounders fluctuated with the season. Values of mercury and arsenic were higher in the fall and values of zinc were higher in the summer. It is not known whether this is related to seasonal changes in faunal physiology or to some physical factors in the environment, such as changes in river flow.

Concentrations of mercury, arsenic, cadmium, copper and zinc were fairly low in the juvenile salmon sampled (Table 3-38). There were no significant differences between levels of metals in specimens from Sturgeon and Roberts Bank (McGreer and Vigers, 1979).

Levels of mercury in salmon from both the river and banks were all close to or below 0.1 µg/g wet weight. Levels in flounders from the Banks were lower than levels detected in other bottom fish from the river, notably largescale sucker, carp, peamouth chub and prickly sculpin (Northcote, Johnston and Tsumura, 1975; McGreer and Vigers, 1979; Drinnan and Northcote, in prep.). The flounders sampled from the Banks were juveniles as opposed to mainly adult bottom fish taken upstream. Mercury concentrations generally increase with increasing age and size of fish before reaching a plateau (Northcote, Johnston and Tsumura, 1975; Manasveta and Siriyong, 1977). Concentrations of arsenic were much higher in flounders from the Banks than in bottom fish from upstream, in which levels were often not detectable (Drinnan and Northcote, in prep.). As indicated previously, arsenic levels are often higher in marine organisms compared to freshwater ones (NRCC, 1978). Zinc and copper were detected at similar levels in fish from the Banks and river.

Levels of mercury in starry flounders from Roberts and Sturgeon Banks were similar to those detected in flounders from Burrard Inlet and Malaspina Strait in B.C. and in winter and yellowtail flounders from the east coast of North America. They were lower than those detected in flounders from the Medway Estuary in England which receives industrial discharges from three cities (Table 3-39). This comparison is very approximate because different species and life stages were involved. Upper range values of arsenic in juvenile flounders from the Banks were lower than concentrations in sole from the coastal waters of Vancouver Island (Table 3-39). Cadmium was often not detectable in tissues of flounders from the Banks, suggesting that it was lower than in flounders or plaice from the Medway Estuary. Levels of zinc and copper in fish from the Banks were similar to levels in specimens from various industrial and non-industrial locations (Table 3-39). It is difficult to assess the implications of these comparisons due to the small amount of data.

3.4 Discussion and Conclusions

The summary of data concerning levels of metals in sediments of the Fraser River presented in this report is not definitive, but provides a baseline for comparison with the results of future studies. Concentrations in sediments were dependent on the particle size composition of the samples and very likely on the organic content of the samples. Changes in the salinity of the waters of the lower river arms will alter the redox potential of the waters and likely influence levels of certain metals in the sediments because redox potential is known to control sorption and coprecipitation of hydrous oxides onto metal ions (Jenne, 1968). Due to these factors, the metal content of sediments is influenced by their position in the estuary, position in the river cross-section or collection location from the mudflats.

Main channel sediments of the North Arm generally contained a larger component of fines than the Main Arm sediments. Main channel sediments of the North Arm also contained higher levels of lead and zinc than the Main Arm. This was related to the particle size differences in the sediments and to the industrial discharges to the North Arm. Levels of metals in backwater sediments were higher than in main channel sediments, probably because of their greater component of fines and higher organic content. Based on the data available, concentrations of metals in sediments could not be related to single point discharges in the river upstream from the Banks. This may be due to a variety of factors. There may have been insufficient sampling around single discharge points. Much of the metals load may remain in suspension in the water column until the effluent plumes have been dispersed. Because of the instability of the river sediments, metal contaminated sediments may be continuously swept downstream, particularly in main river channel situations, preventing accumulation near the discharge point.

Levels of metals in sediments of the Banks were of the same orders of magnitude as those from the downstream portions of the river arms. Concentrations of certain metals were significantly higher in sediments proximal to the Iona Island STP outfall compared to elsewhere on the Banks. This was mainly attributed to metals discharged with the fine, organically enriched particles in suspension in the effluent, which subsequently settled out in the vicinity of the outfall.

Baseline data were collected on levels of metals in algae, benthic and epibenthic invertebrates and fish. Oligochaetes (tubificids) and chironomid larvae consistently bioconcentrated mercury and at certain sites, zinc and copper, to levels above those detected in the sediments. Generally levels of metals detected in fish from the river did not show regional patterns, with the exception of zinc which appeared to be higher in fish from the North Arm than from elsewhere in the river. Levels of mercury were sometimes higher than the enforcement level for human consumption in certain bottom fish from each region of the river downstream from Hope. Levels of metals were generally low in the small number of salmon sampled from the river. It is impossible at this time to relate metal accumulation in the biota of the river (Mainstem, North Arm, Main Arm) to single point discharges.

Sampling of biota from the mudflats for metals has been conducted more intensively than sampling of biota in the river. In a zone of Sturgeon Bank affected by the Iona Island STP effluent, a number of metals in attached algae and bivalves were elevated, above those in specimens from other areas of the mudflats. The behaviour of the bivalve Macoma balthica was altered by metal contaminated sediments and this clam bioconcentrated copper, zinc and mercury above levels in the sediments in an area proximal to the outfall.

A small number of juvenile chinook salmon from the Banks were monitored and concentrations of metals in them were not considered to be of concern.

Mercury was detected at levels nearing the enforcement level for edible tissue (0.5 µg/g wet weight) in bivalves and at times exceeded it in crabs (Cancer magister) collected near the Iona Island STP outfall. Levels in crabs taken from other parts of Sturgeon Bank and Roberts Bank also approached 0.5 µg/g wet weight. Concentrations of mercury in juvenile starry flounders followed a similar pattern, although they did not reach 0.5 µg/g wet weight. This suggested that the Iona Island STP was one likely source of mercury contamination to the mudflats, but not the only source.

Biological information from the study area showed that mercury, as a contaminant, is worthy of further investigation. All sources of mercury to the Fraser have not been identified. There are major deposits of mercury in the upstream watershed north of Lillooet and Prince George (Fish and Wildlife Branch), and inputs of geochemical mercury from these natural sources may be significant to the study area. Seemingly small amounts and biologically unavailable forms of mercury can be made toxic and readily available for biological uptake through microbial activity (Jernelov, 1972a). After oxidation of elemental mercury or breakdown of phenylmercury, the mercuric ion may be biologically methylated (Landner, 1971; Spangler et al., 1973). Much biological methylation by micro and macroorganisms (fungi and possibly invertebrates) takes place in sediments where dense mercury compounds settle out (Jernelov, 1972a; Spangler et al., 1973). Methyl mercury, a highly toxic form of mercury, is readily accumulated by fish and other aquatic organisms and can be released to the water column from the sediments (Jernelov, 1972a). Based on work from other watersheds, methyl mercury from water was estimated to account for 50 percent of the mercury accumulated by northern pike and 90 percent accumulated by whitefish, the remaining portions being derived from food (Jernelov, 1972b).

Biological methylation is controlled by a variety of factors including temperature, pH, redox potential, organic matter and mercuric ion concentration (Bisogni and Lawrence, 1975). High concentrations of hydrogen sulphide, common in sediments near sewage outfalls, particularly intertidal ones, may have a debilitating effect on methylating organisms. Numbers of bacteria may be reduced and methyl mercury may be absent from areas adjacent to outfalls (Eganhause et al., 1978).

In summary, small amounts of mercury can be significant in the process of biological accumulation, but this process and the sources of mercury in the Fraser River study area have not been completely studied.

Levels of arsenic in organisms from the Banks were often greater than in organisms from the river where levels were often not detectable in fish. Background levels of arsenic can be much higher in marine crustaceans (Zook et al., 1976) and fish (NRCC, 1978), compared to freshwater species. More data on ambient levels of arsenic in marine organisms from a variety of locations in British Columbian waters would be needed to substantiate this finding locally.

Based on the present data, levels of metals in riverine algae and benthic invertebrates showed no seasonal fluctuations. Certain metals did fluctuate with season in crabs (C. magister) and juvenile starry flounders from the Banks.

Research has begun on understanding the relative importance to aquatic biota of each source of metals, namely, the water column, the sediments and food, but is far from complete. Much more effort is needed to assess the exchange of metals between sediments and overlying or interstitial waters and the biologically important forms of metals in sediments and receiving waters. Metal levels were shown to change with season in certain organisms, which may be related to a number of factors such as physiological and behavioural changes in organisms or physical changes in the environment.

Most metals are required in trace amounts for normal physiological functions. However the mechanisms are not completely known by which aquatic organisms can tolerate or deal with metals that are accumulated or bioconcentrated above the trace amounts. The physiological impacts of excess metals are not well understood. Evidence is growing to show that a protein, metallothionein, produced during times of metallic "overloads", may be able to detoxify metals by binding them to cystine residues (Bremner and Davies, 1975). This detoxifying system may operate in zooplankton and chum salmon exposed to low levels of mercury over long periods of time (Brown and Parsons, 1978) and likely exists in other organisms. As previously indicated (Section 3.1) the degree of sublethal or chronic toxicities of metals to aquatic biota of the Fraser River and estuary is not well known.

Some earlier studies referenced in this report were prepared before 1979 and used the Food and Drug Act regulations published by the federal government in 1975 (Table 3-30) to interpret their data (Northcote, Johnston and Tsumura, 1975; McGreer and Vigers, 1979). In 1979 these regulations were changed and the food category "marine and freshwater animal products" was omitted (refer to Table 3-30). It was felt that a single regulation could not encompass such a broad group of organisms. When investigations are conducted regarding potential health hazards, the Health Protection Branch, Health and Welfare Canada, now analyses a protein extract of the fish tissue in question for metals. The metals copper and zinc have been omitted from the regulations for all categories of foods partly because they had not appeared as general nation-wide problems in foods. The loss of any regulations for fish and shellfish tissues makes interpretation of metal levels in edible species impossible because most laboratory analyses are based on mass of metals in whole tissues and not specifically on protein extracts.

The administrative guideline level for mercury used for enforcement by the Health Protection Branch, Health and Welfare Canada, for fish and shellfish remains at 0.5 μg/g wet weight. The current "action level" used by the U.S. Food and Drug Administration is 1.0 μg/g wet weight (Federal Register, Friday, January 19, 1979). Average levels of mercury in British coastal fish exceeded 0.5 μg/g (wet weight) and were closer to 1.0 μg/g (Leatherland and Burton, 1974). Although the task of setting guidelines for levels of metals in edible products is obviously a very difficult one, and includes assessing ambient metal concentrations in fish and shellfish, the need for guidelines remains.

Consideration should now be given as to whether analysing epaxial muscle is appropriate for monitoring bioaccumulation of metals in fish or whether other tissues should be analysed in addition to or instead of muscle. Perhaps extracts of protein from edible species of biota should be analysed in the future for arsenic and lead so these could be compared to the Food and Drugs Act Regulations (Health and Welfare Canada).

CHAPTER 4 RECOMMENDATIONS AND RESEARCH AND MONITORING PROGRAMS

4.1 Recommendations

1) It has been shown that backwater areas in the lower Fraser River are important habitat for salmonids and for the biota on which they depend for food. These areas must be identified and due to conditions imposed by poor water exchange, efforts must be made to prevent adverse changes in their water quality. Discharges of wastes to backwaters must be minimized or eliminated to maintain or restore natural conditions of water quality, habitat and biological populations.

2) The mudflats of Sturgeon and Roberts Banks support large, diverse populations of biota. It has been shown that the fauna of Sturgeon Bank have been detrimentally altered in a certain area, due to the Iona Island STP discharge. Treatment of the sewage discharged from the Iona Island plant should be upgraded, either by further treatment at the existing site or by relocating the outfall so that it discharges in Georgia Strait, to allow rehabilitation of the affected area and the associated biota.

Alterations to the biota of the remainder of Sturgeon Bank or to Roberts Bank should be prevented.

3) Data have shown that copper, zinc and mercury were bioconcentrated by certain organisms in the Fraser River study area. Levels of mercury were close to or exceeded the maximum level recommended as safe for consumption by the Canadian Food and Drug Directorate, in a few fish species from the river (northern squawfish, prickly sculpin, white sturgeon, largescale sucker and peamouth chub) and crabs from the Banks. A comprehensive source control program should be applied to major discharges of metals in the study area to possibly reduce metal levels in some portions of the river or to prevent the increase of levels in cases where the major sources are not controllable.

4) A number of major data gaps exist including an understanding of the effects of municipal sewage treatment plants on the receiving environment and biota of the river. These should be filled through investigations, such as the research projects and monitoring studies outlined in the following section, 4.2.1. Routine monitoring of levels of metals in biota and sediments should be conducted as suggested in the following section (4.2.2), to coincide with the monitoring programs recommended by Drinnan and Clark

(1980) and Garrett (1980). Any further studies of biological communities designed to assess water quality in the study area of the Fraser River and tidal mudflats should be undertaken with clear objectives, and should be intensive and well defined. General monitoring of communities and their diversities is no longer recommended, but monitoring of communities associated with specific sites or areas is recommended.

4.2 Research and Monitoring Program

4.2.1 Research Projects and Monitoring Studies

The following is a list of studies which fall into the category of research, and which supplement the suggested monitoring progam outlined in Section 4.3.2. They are not ranked in order of importance, but rather follow the order imposed by the organization of this report.

1) Natural populations in the riverine portion of the Fraser River Estuary may not show changes or differences solely due to anthropogenic influences because of the complex and fluctuating conditions imposed on them by the estuarine environment. Monitoring natural sedentary biota upstream and downstream from any effluent (or at a "control" and discharge point), will likely not give meaningful information about the impacts of that effluent on the receiving environment. This does not apply to the intertidal portion of the study area, Sturgeon and Roberts Banks. Methods such as those mentioned below in (2) should be investigated to assess the effects of such impacts as discharges in the riverine part of the estuary.

2) There have been few studies conducted on the possible effects of the sewage from the Annacis Island sewage treatment plant (or Lulu) on biota, with the exception of the acute fish toxicity tests as described by Singleton (1980). Different methods of evaluation should be tried and used to gain a better understanding of any impacts. Other organisms, such as invertebrates should be considered for use in acute bioassays, in addition to fish, if shown to be more sensitive indicators.

Another toxicity test worth investigating for use in the Fraser River is the algal bottle test (bioassay). It is under continual evaluation by the U.S. Environmental Protection Agency for its usefulness in assessing the effects of waste discharges on receiving waters and for methods of standardizing the test.

The use of certain chronic toxicity tests where physiological stress, measured by such functions as metabolic rates (as opposed to an organism's death) should be investigated as an indicator of the effects of effluents.

The use of population analyses of periphyton (algal and protozoan), collected on artificial substrate placed in either the receiving waters or simulated environmental conditions should be examined. Heterotrophic activity as an indicator of conditions of the receiving waters may have potential for use.

All biological monitoring should be conducted in conjunction with comprehensive assessment of the chemistry of the effluents and receiving waters.

3) The impact of individual discharges, particularly stormwater and landfill leachates, on water chemistry and biota should be determined.

4) The effects on benthic and epibenthic invertebrates of wood wastes and debris covering the substrate, have not been determined in the study area. These should be investigated, particularly in backwaters.

5) The locations, frequency and magnitude of accidental spills and non-permitted discharges should be documented continuously and as completely as possible.

6) The systematics (taxonomy) of immature chironomids in the study area should be worked out. These are important components of the diets of juvenile salmon yet the species of importance have not been identified.

7) Although a complex research program would be necessary, the debate regarding possible increased primary productivity in the Strait of Georgia and its relationship to sewage treatment practices in the study area should be resolved.

8) Mechanisms of contaminant transport from receiving components of the aquatic environment (water, sediments) to biota, and subsequent movement in the food web are poorly understood. More effort should be directed toward understanding the bioavailability of metals in sediments, the best methods of measuring reactive forms and the cycling of contaminants from receiving waters to sediments and from sediments to receiving waters. Although it is beyond the scope of this report to identify all such studies, research exploring bioavailability of contaminants and their cycling should be encouraged and supported.

9) For a better understanding of metal transport in the food chain, further investigation of metal concentrations in epibenthic species, such as amphipods and mysids, should be made.

10) Sources of mercury to the study area should be identified if possible, and the loading from each source determined. If significant sources to the river are identified, the receiving environment (water, sediments, biota) should be sampled to assess the impact.

11) With the above information, and taking into account their behavioural and physiological characterstics, the significance of levels of mercury in certain fish and crabs should be determined.

12) Fish should be collected upstream from Hope (e.g., near Prince George, Williams Lake and Lillooet) and analysed for metals, particularly mercury, copper and zinc. An attempt should be made to monitor the same species collected downstream such as white sturgeon, largescale sucker, peamouth chub, northern squawfish and prickly sculpins.

13) The relative merits of sampling fish tissues in other than epaxial muscle, when assessing the cycling of contaminants should be considered. Consideration should be given to analysing fish protein to compare with the Food and Drugs Act Regulations (Health and Welfare Canada).

14) Appropriate agencies should address the topic of assessment of sublethal or chronic stress in organisms. It should be determined whether sublethal or chronic tests are available for use in researching levels of contaminants in the Fraser River and if so how they should be used in assessing these parameters in the study area. This is a consideration separate from assessing the impact in the plumes of various site specific effluents, and refers to the study area in general.

4.2.2 Routine Monitoring Program for Biota and Sediments

Levels of metals should be monitored regularly in the aquatic biota of the Lower Fraser River. The program will yield historical information, that is, it will determine whether concentrations of certain contaminants increase or decrease over time. It will also expand knowledge of the fate of contaminants in the food chain and provide information regarding levels of certain metals in edible aquatic tissues.

It is suggested that biota be monitored for metals every five years, beginning between 1981 and 1983. This should complement the monitoring programs suggested for organic contaminants (Garrett, 1980) and water chemistry (Drinnan and Clark, 1980). Table 4-1 outlines a monitoring regime. A recommended list of metals includes cadmium, copper, lead, manganese, mercury, zinc and the metalloid arsenic. This list should be reassessed after each sampling program.

The distribution of certain organisms and the biomass requirements for tissue analyses limit the range of biota which can be monitored. Considering these limitations, periphyton, tubificids (oligochaetes), immature chironomids, amphipods, bivalves, crabs and fish (duplicating the species monitored by Northcote, Johnston and Tsumura (1975) and McGreer and Vigers (1979) as closely as possible) should be analysed. More salmon (both adults and juveniles) should be sampled in future collections. Refer to Table 4-1 and Figure 29 for suggested sampling sites.

When possible, samples should be composed of a single species because each species accumulates different amounts of metals at certain rates. If samples contain a mixture of species (e.g., mixed species of periphyton, tubificids, and chironomids), the dominant species in each should be determined.

Sediment samples should be taken and analysed simultaneously with the benthos. A consistent uniform method of sampling should be adopted, such as a coring technique which will make constant such variables as volume and depth of sample. Particle sizes, percent organic carbon and contaminant content of sediment samples should be determined, also in a consistent manner. Refer to Table 4-1 for suggested sampling regime.

Collection and analysis of biological samples is extremely costly. Metal levels in some organisms, such as fish and crabs from the Banks showed seasonal cycling. Seasonal fluctuations should be apparent if sampling is conducted twice a year, once in the late winter and once in the summer. For the first year program twice a year is recommended. This frequency may be reduced to once a year in subsequent years if suggested by the results. Laboratory procedures utilizing the minimal amount of tissue necessary to provide useful detection limits for test compounds should be developed and adopted. Sample sizes and/or the number of replications should be established to produce the most reliable data for the best use of funds. Similar methods should be used by all laboratories involved and these laboratories should be intercalibrated.

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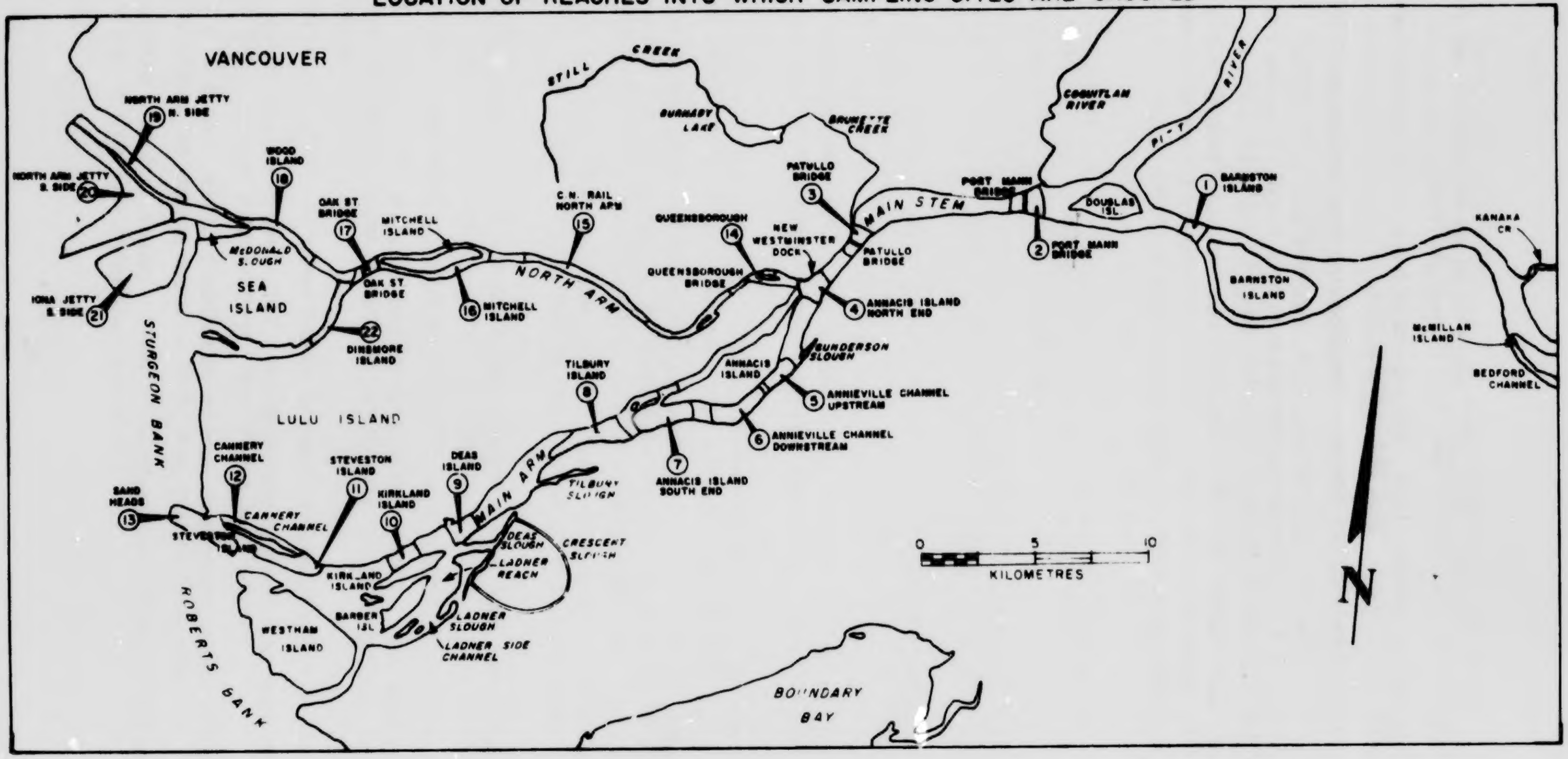
FIGURE 1

LOCATION OF REACHES INTO WHICH SAMPLING SITES ARE GROUPED


VANCOUVER
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
COQUITLAM RIVER
PITT RIVER
KANAKA CR
McMILLAN ISLAND
BEDFORD CHANNEL
1 BARNSTON ISLAND
BARNSTON ISLAND
DOUGLAS ISL
PORT MANN BRIDGE
2 PORT MANN BRIDGE
MAIN STEM
PATULLO BRIDGE
3
PATULLO BRIDGE
NEW WESTMINSTER DOCK
4 ANNACIS ISLAND NORTH END
QUEENSBOROUGH
14
QUEENSBOROUGH BRIDGE
GUNDERSON SLOUGH
ANNACIS ISLAND
5 ANNIEVILLE CHANNEL UPSTREAM
6 ANNIEVILLE CHANNEL DOWNSTREAM
7
ANNACIS ISLAND SOUTH END
TILBURY ISLAND
8
TILBURY SLOUGH
C.N. RAIL NORTH ARM
15
NORTH ARM
16 MITCHELL ISLAND
MITCHELL ISLAND
OAK ST BRIDGE
17
OAK ST BRIDGE
WOOD ISLAND
18
NORTH ARM JETTY N. SIDE
19
NORTH ARM JETTY S. SIDE
20
IONA JETTY S. SIDE
21
McDONALD SLOUGH
SEA ISLAND
22
DINSMORE ISLAND
STURGEON BANK
LULU ISLAND
CANNERY CHANNEL
12
CANNERY CHANNEL
STEVESTON ISLAND
11
KIRKLAND ISLAND
10
DEAS ISLAND
9
MAIN ARM
SAND HEADS
13
STEVESTON ISLAND
KIRKLAND ISLAND
BARBER ISL
WESTHAM ISLAND
DEAS SLOUGH
CRESCENT SLOUGH
LADNER REACH
LADNER SLOUGH
LADNER SIDE CHANNEL
ROBERTS BANK
BOUNDARY BAY
0
5
10
KILOMETRES
N

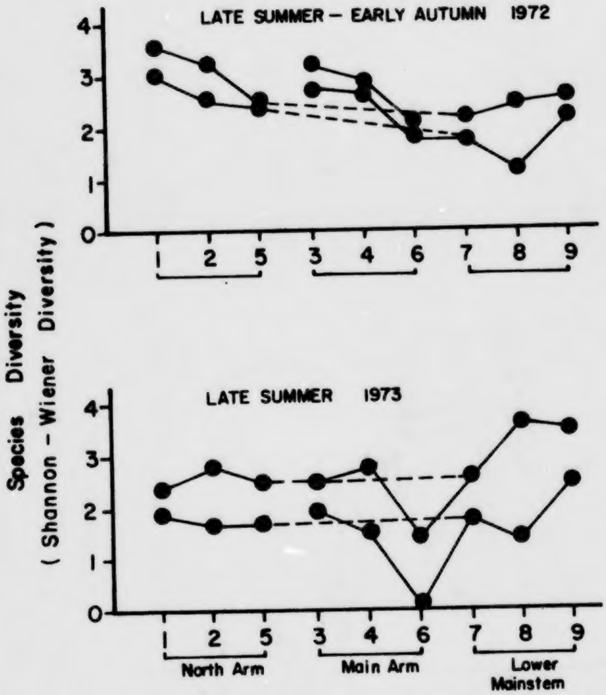
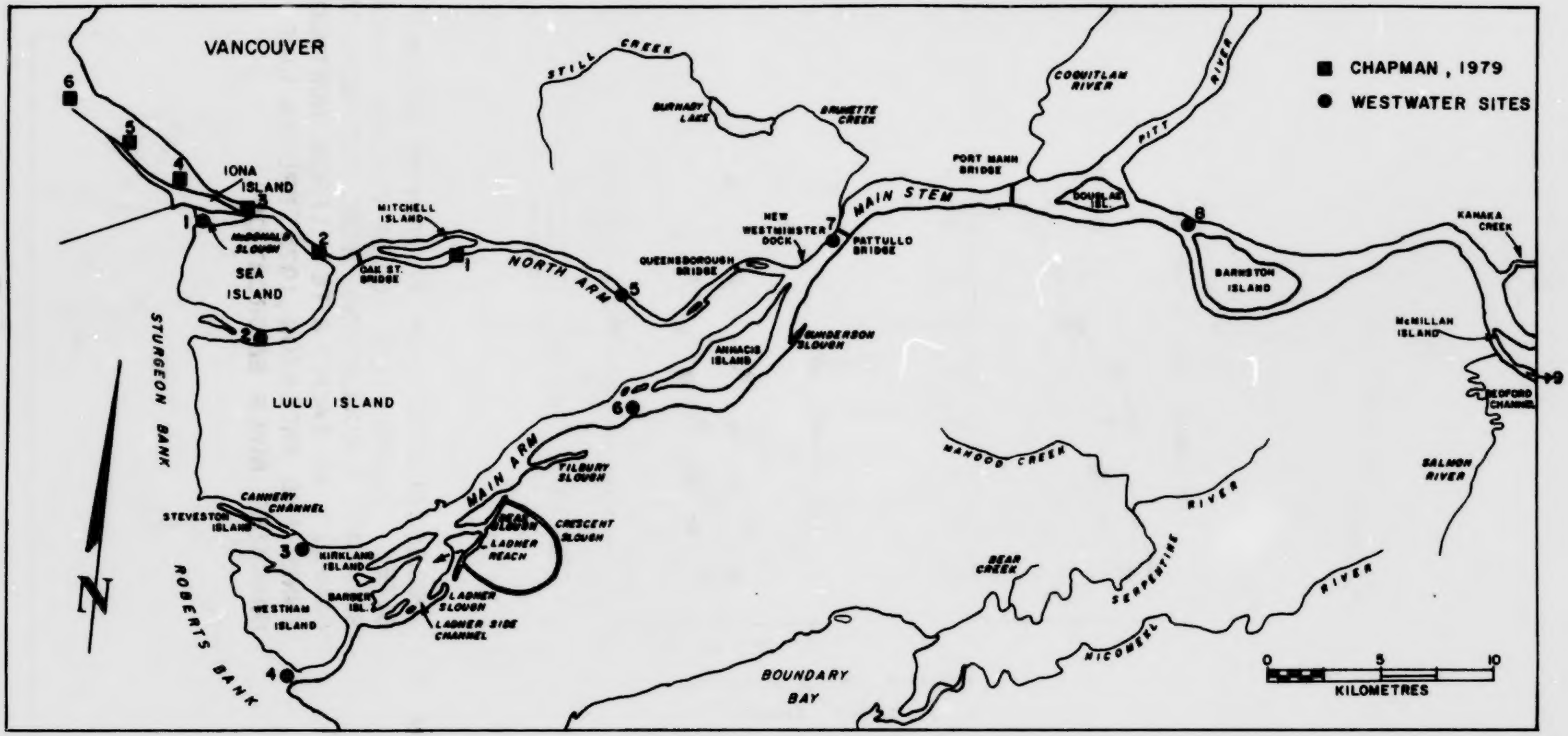


FIGURE 2 . SPECIES DIVERSITY OF PERIPHYTIC DIATOMS AT SITES ALONG THE LOWER FRASER RIVER. SEPARATE CALCULATIONS MADE FOR REPLICATE SAMPLES AT EACH SITE .(FROM NORTHCOTE, ENNIS AND ANDERSON, 1975. BROKEN LINE INDICATES RIVER BIFURCATION).

FIGURE 3.

SAMPLE SITES USED BY WESTWATER RESEARCH CENTER AND CHAPMAN (1979)


■ CHAPMAN, 1979
● WESTWATER SITES
VANCOUVER
IONA ISLAND
McDONALD SLOUGH
SEA ISLAND
STURGEON BANK
LULU ISLAND
MITCHELL ISLAND
OAK ST. BRIDGE
NORTH ARM
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
QUEENSBOROUGH BRIDGE
NEW WESTMINSTER DOCK
PATTULLO BRIDGE
MAIN STEM
PORT MANN BRIDGE
COQUITLAM RIVER
PITT RIVER
DOUGLAS ISL.
BARNSTON ISLAND
KANAKA CREEK
McMILLAN ISLAND
BEDFORD CHANNEL
SALMON RIVER
ANNACIS ISLAND
GUNDERSON SLOUGH
MAIN ARM
TILBURY SLOUGH
CRESCENT SLOUGH
DEAS SLOUGH
LADNER REACH
LADNER SLOUGH
LADNER SIDE CHANNEL
CANNERY CHANNEL
STEVESTON ISLAND
KIRKLAND ISLAND
BARBER ISL.
WESTHAM ISLAND
ROBERTS BANK
BOUNDARY BAY
MAHOOD CREEK
SERPENTINE RIVER
BEAR CREEK
NICOMEKL RIVER
N
0
5
10
KILOMETRES
1
2
3
4
5
6
7
8
9

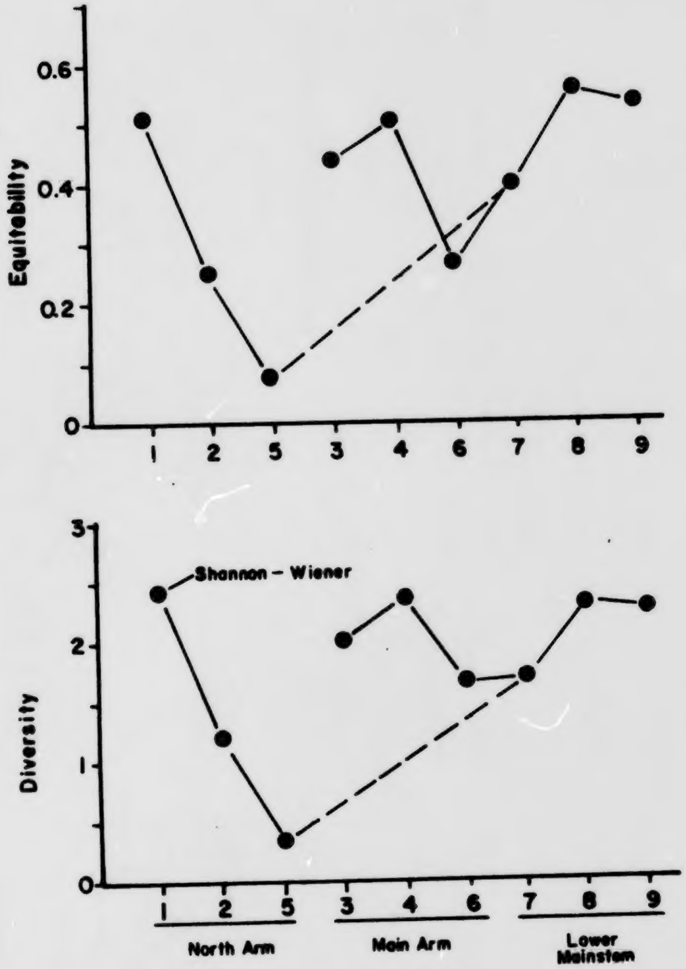


FIGURE 4 . CUMULATIVE DIVERSITY OF THE BENTHIC FAUNA OF THE LOWER FRASER RIVER . (FROM NORTHCOTE , JOHNSTON AND TSUMURA, 1976. BROKEN LINE INDICATES RIVER BIFURCATION) .

FIGURE 5

LOCATION OF MUNICIPAL SEWAGE TREATMENT PLANT DISCHARGES AND LANDFILLS.

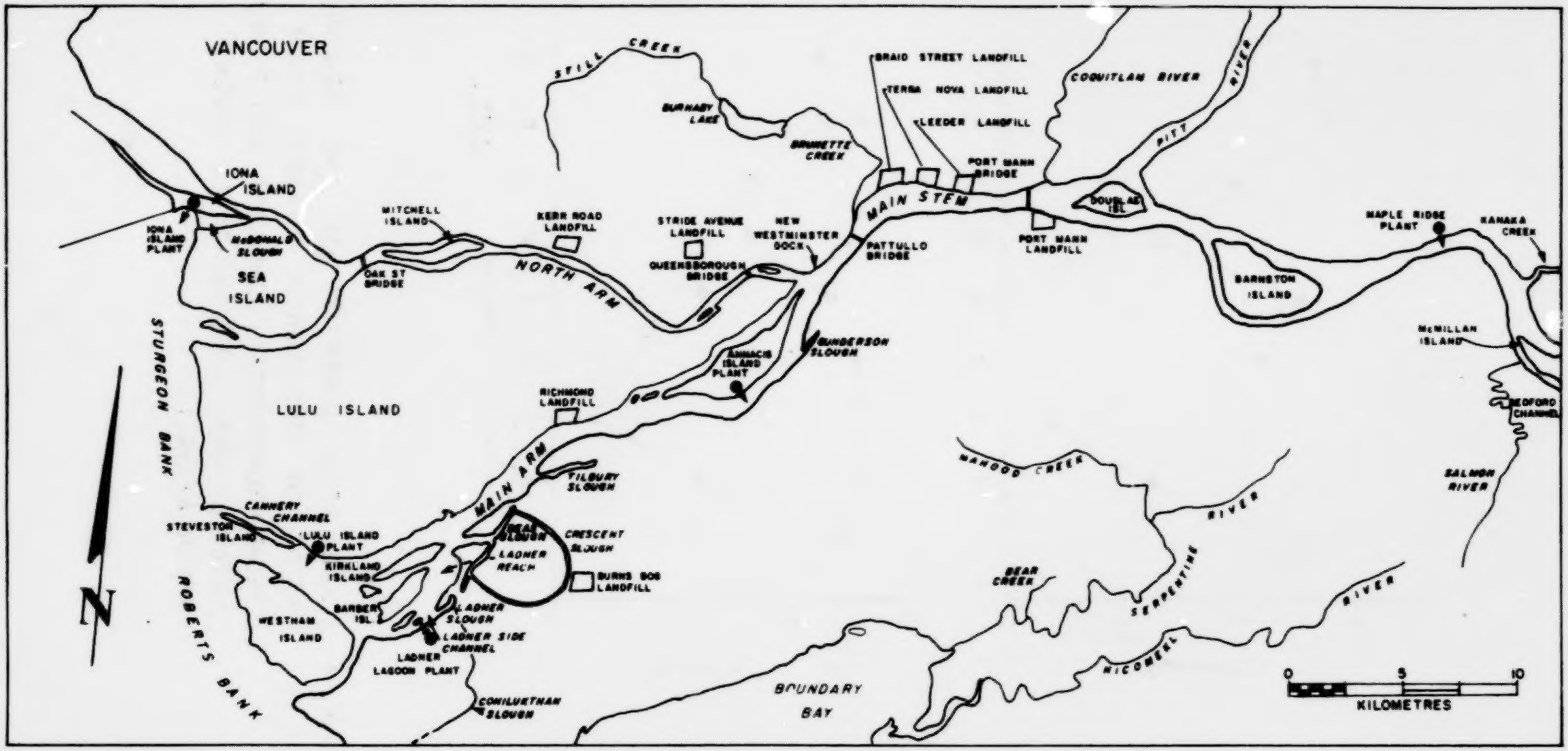

VANCOUVER
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
BRAID STREET LANDFILL
TERRA NOVA LANDFILL
LEEDER LANDFILL
PORT MANN BRIDGE
COQUITLAM RIVER
PITT RIVER
DOUGLAS ISL
MAPLE RIDGE PLANT
KANAKA CREEK
IONA ISLAND
IONA ISLAND PLANT
McDONALD SLOUGH
SEA ISLAND
MITCHELL ISLAND
OAK ST BRIDGE
KERR ROAD LANDFILL
NORTH ARM
STRIDE AVENUE LANDFILL
QUEENSBOROUGH BRIDGE
NEW WESTMINSTER DOCK
MAIN STEM
PATTULLO BRIDGE
PORT MANN LANDFILL
BARNSTON ISLAND
McMILLAN ISLAND
BEDFORD CHANNEL
SALMON RIVER
STURGEON BANK
LULU ISLAND
ANNACIS ISLAND PLANT
GUNDERSON SLOUGH
RICHMOND LANDFILL
MAIN ARM
TILBURY SLOUGH
CANNERY CHANNEL
STEVESTON ISLAND
LULU ISLAND PLANT
KIRKLAND ISLAND
DEAS SLOUGH
CRESCENT SLOUGH
LADNER REACH
BURNS BOG LANDFILL
BARBER ISL.
LADNER SLOUGH
LADNER SIDE CHANNEL
LADNER LAGOON PLANT
WESTHAM ISLAND
ROBERTS BANK
COHILUKTHAN SLOUGH
NAHOOD CREEK
BEAR CREEK
SERPENTINE RIVER
NICOMEKL RIVER
BOUNDARY BAY
0
5
10
KILOMETRES
N

FIGURE 6
LOCATION OF STORM SEWER OUTFALLS

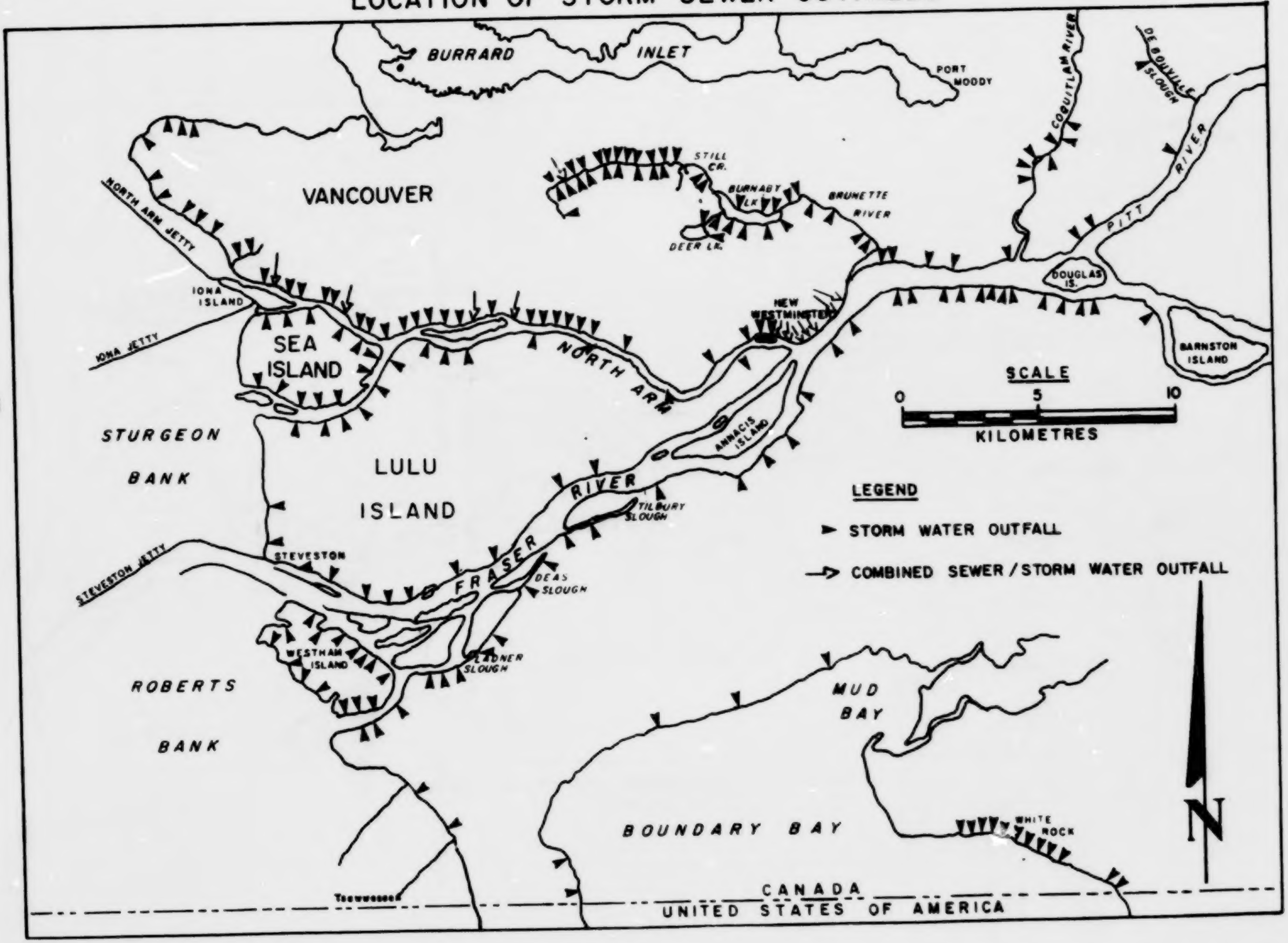
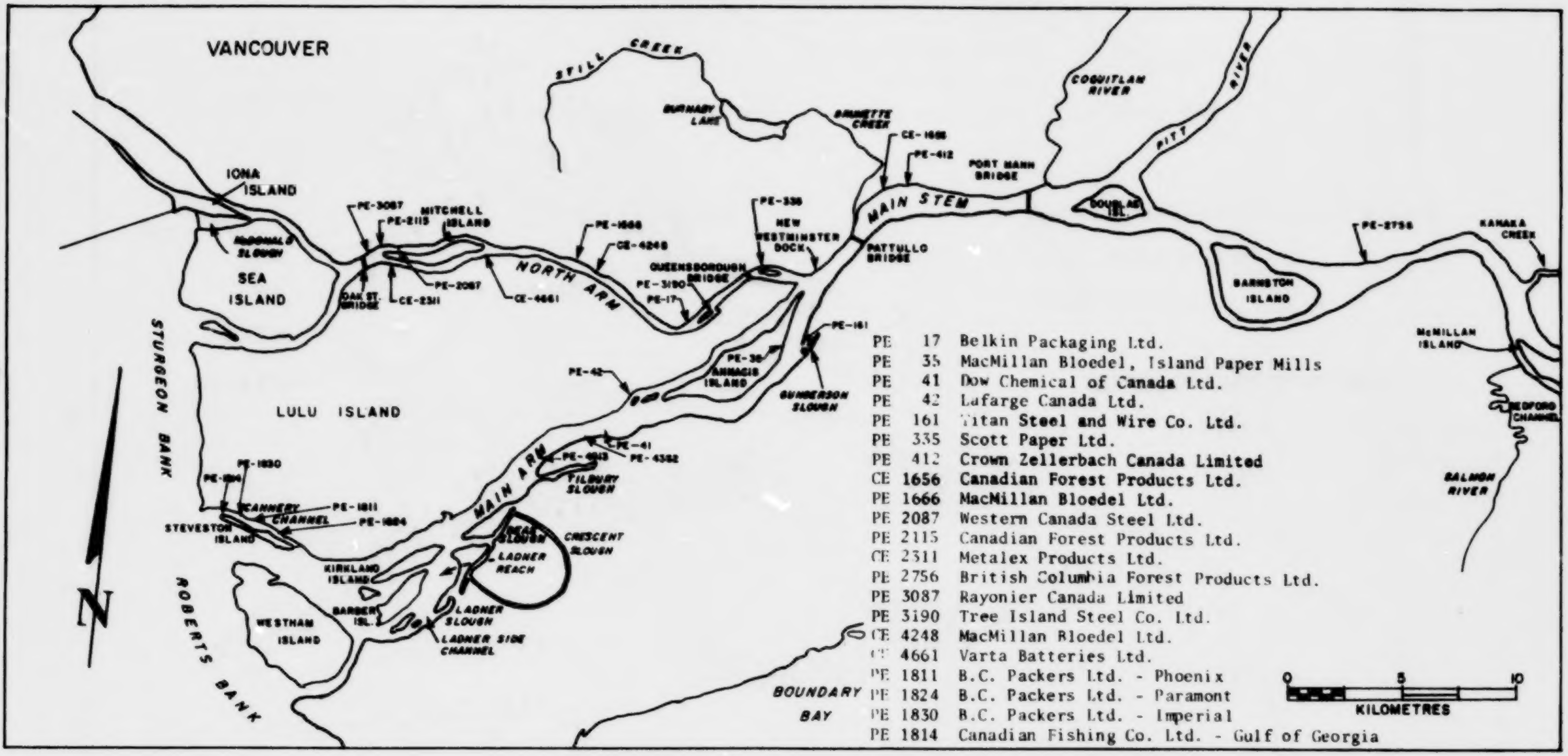
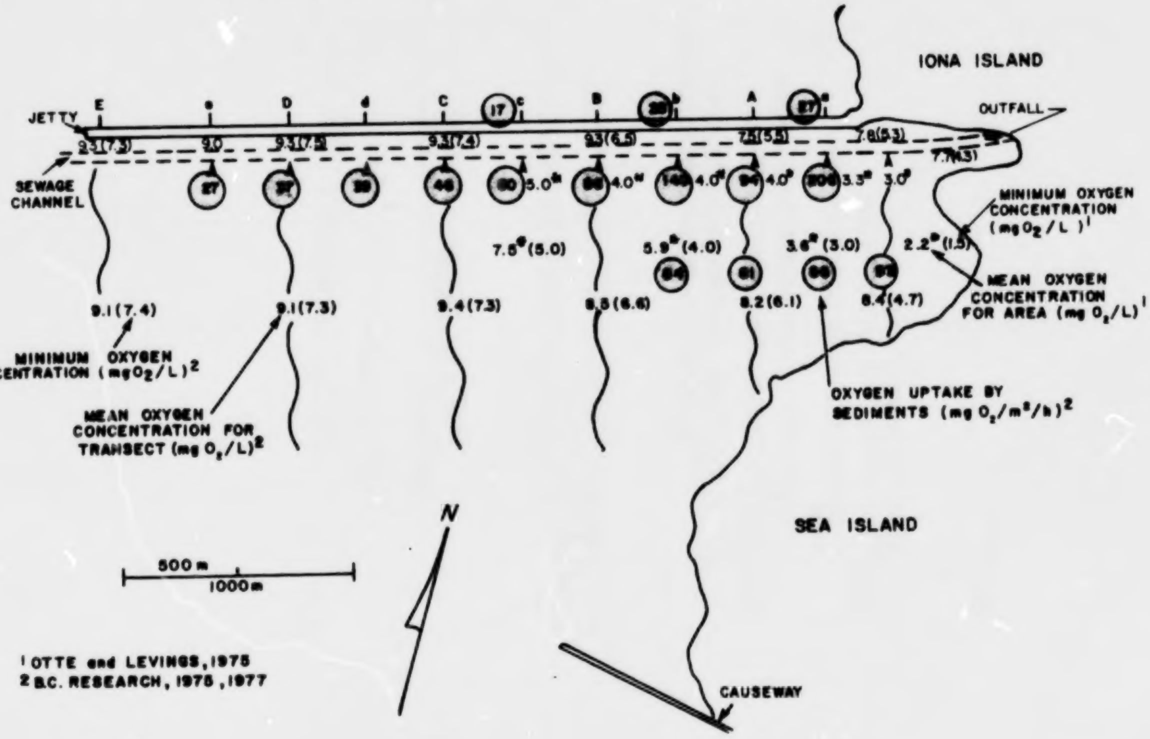

BURRARD INLET
PORT MOODY
COQUITLAM RIVER
DE BOUVILLE SLOUGH
PITT RIVER
VANCOUVER
NORTH ARM JETTY
STILL CR.
BURNABY LK.
DEER LK.
BRUNETTE RIVER
IONA ISLAND
IONA JETTY
SEA ISLAND
NEW WESTMINSTER
DOUGLAS IS.
BARNSTON ISLAND
NORTH ARM
SCALE
0
5
10
KILOMETRES
STURGEON BANK
LULU ISLAND
ANNACIS ISLAND
FRASER RIVER
TILBURY SLOUGH
LEGEND
► STORM WATER OUTFALL
→ COMBINED SEWER / STORM WATER OUTFALL
STEVESTON
STEVESTON JETTY
DEAS SLOUGH
WESTHAM ISLAND
LADNER SLOUGH
ROBERTS BANK
MUD BAY
BOUNDARY BAY
WHITE ROCK
N
CANADA
UNITED STATES OF AMERICA

FIGURE 7
LOCATION OF MAJOR INDUSTRIAL DISCHARGES


VANCOUVER
IONA ISLAND
McDONALD SLOUGH
SEA ISLAND
STURGEON BANK
LULU ISLAND
ROBERTS BANK
STEVESTON ISLAND
CANNERY CHANNEL
WESTHAM ISLAND
KIRKLAND ISLAND
BARBER ISL.
LADNER SLOUGH
LADNER SIDE CHANNEL
LADNER REACH
CRESCENT SLOUGH
TILBURY SLOUGH
MAIN ARM
ANNACIS ISLAND
GUNDERSON SLOUGH
BOUNDARY BAY
NORTH ARM
MITCHELL ISLAND
OAK ST. BRIDGE
QUEENSBOROUGH BRIDGE
NEW WESTMINSTER DOCK
PATTULLO BRIDGE
MAIN STEM
PORT MANN BRIDGE
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
COQUITLAM RIVER
PITT RIVER
DOUGLAS ISL.
BARNSTON ISLAND
KANAKA CREEK
McMILLAN ISLAND
BEDFORD CHANNEL
SALMON RIVER
PE-3087
PE-2115
PE-2087
CE-2311
CE-4661
PE-1666
CE-4248
PE-3190
PE-17
PE-335
CE-1656
PE-412
PE-161
PE-35
PE-42
PE-41
PE-1830
PE-1814
PE-1811
PE-1824
PE-2756
N
0
5
10
KILOMETRES

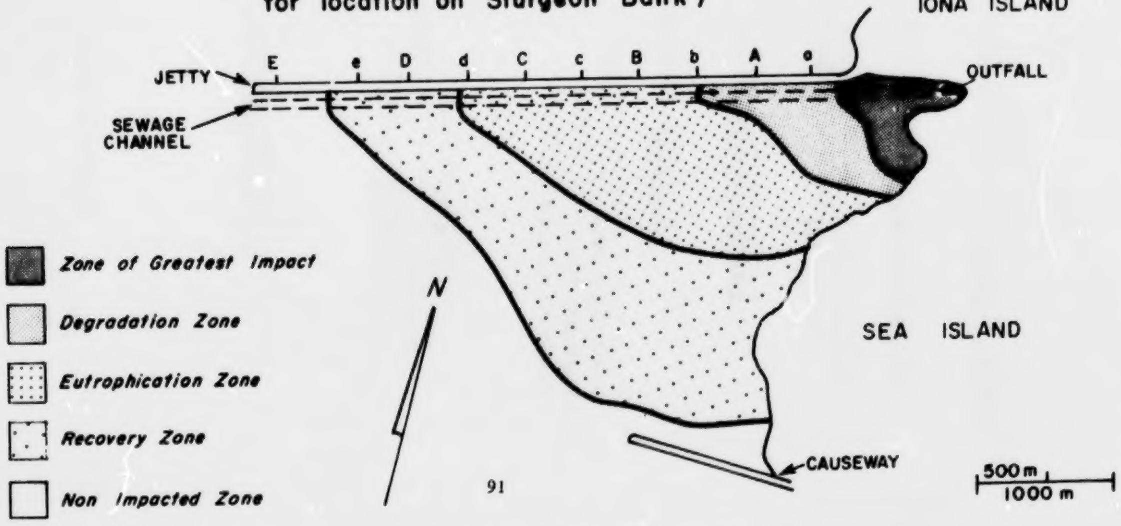
PE	17	Belkin Packaging Ltd.
PE	35	MacMillan Bloedel, Island Paper Mills
PE	41	Dow Chemical of Canada Ltd.
PE	42	Lafarge Canada Ltd.
PE	161	Titan Steel and Wire Co. Ltd.
PE	335	Scott Paper Ltd.
PE	412	Crown Zellerbach Canada Limited
CE	1656	Canadian Forest Products Ltd.
PE	1666	MacMillan Bloedel Ltd.
PE	2087	Western Canada Steel Ltd.
PE	2115	Canadian Forest Products Ltd.
CE	2311	Metalex Products Ltd.
PE	2756	British Columbia Forest Products Ltd.
PE	3087	Rayonier Canada Limited
PE	3190	Tree Island Steel Co. Ltd.
CE	4248	MacMillan Bloedel Ltd.
CE	4661	Varta Batteries Ltd.
PE	1811	B.C. Packers Ltd. - Phoenix
PE	1824	B.C. Packers Ltd. - Paramont
PE	1830	B.C. Packers Ltd. - Imperial
PE	1814	Canadian Fishing Co. Ltd. - Gulf of Georgia

FIGURE 8. THE OXYGEN REGIME OF RECEIVING WATERS AND SEDIMENTS OF STURGEON BANK NEAR THE IONA STP OUTFALL


IONA ISLAND
JETTY
E
e
D
d
C
17
c
B
b
A
a
OUTFALL
9.3(7.3)
9.0
9.3(7.5)
9.3(7.4)
9.3(6.5)
7.5(5.5)
7.8(5.3)
7.7(4.3)
SEWAGE CHANNEL
27
5.0*
4.0*
4.0*
4.0*
3.3*
3.0*
MINIMUM OXYGEN CONCENTRATION (mg O2 / L)1
7.5*(5.0)
5.9*(4.0)
3.6*(3.0)
2.2*(1.5)
81
MEAN OXYGEN CONCENTRATION FOR AREA (mg O2/L)1
9.1(7.4)
9.1(7.3)
9.4(7.3)
8.5(6.6)
8.2(6.1)
8.4(4.7)
MINIMUM OXYGEN CONCENTRATION (mg O2/L)2
MEAN OXYGEN CONCENTRATION FOR TRANSECT (mg O2/L)2
OXYGEN UPTAKE BY SEDIMENTS (mg O2/m2/h)2
SEA ISLAND
N
500 m
1000 m
CAUSEWAY

1 OTTE and LEVINGS, 1975
2 B.C. RESEARCH, 1975, 1977

FIGURE 8a. ZONES OF IMPACT RESULTING FROM THE IONA STP DISCHARGE * (Refer to Figure 10 for location on Sturgeon Bank)


IONA ISLAND
JETTY
E
e
D
d
C
c
B
b
A
a
OUTFALL
SEWAGE CHANNEL
Zone of Greatest Impact
Degradation Zone
Eutrophication Zone
Recovery Zone
Non Impacted Zone
N
SEA ISLAND
CAUSEWAY
500 m
1000 m

* Compiled from data in B.C. Research, 1973; 1975; 1977 and Otte and Levings, 1975

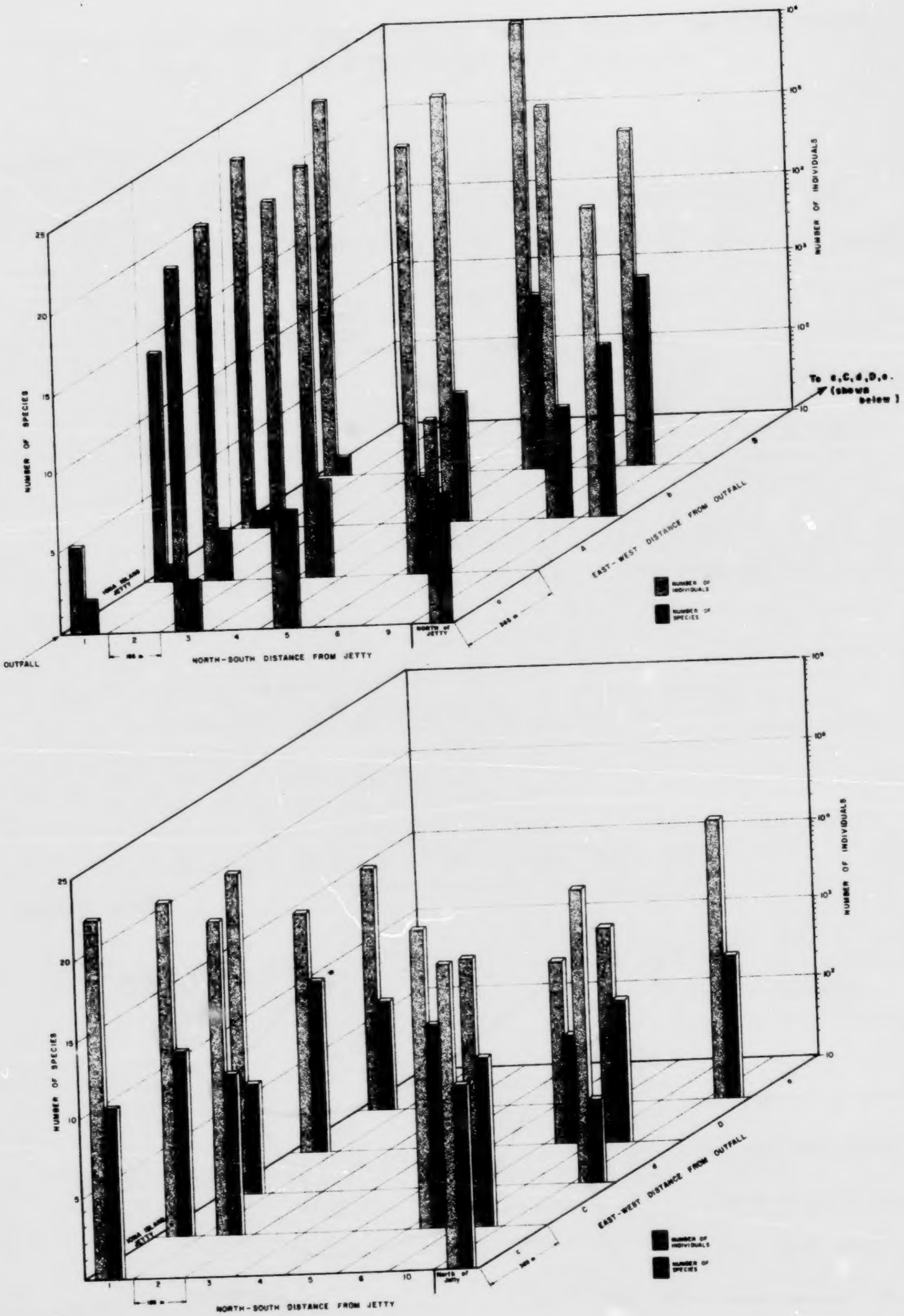


FIGURE 9. NUMBERS OF SPECIES AND INDIVIDUALS OF MACROINVERTEBRATES SAMPLED AT IONA ISLAND (B.C. RESEARCH, 1977)

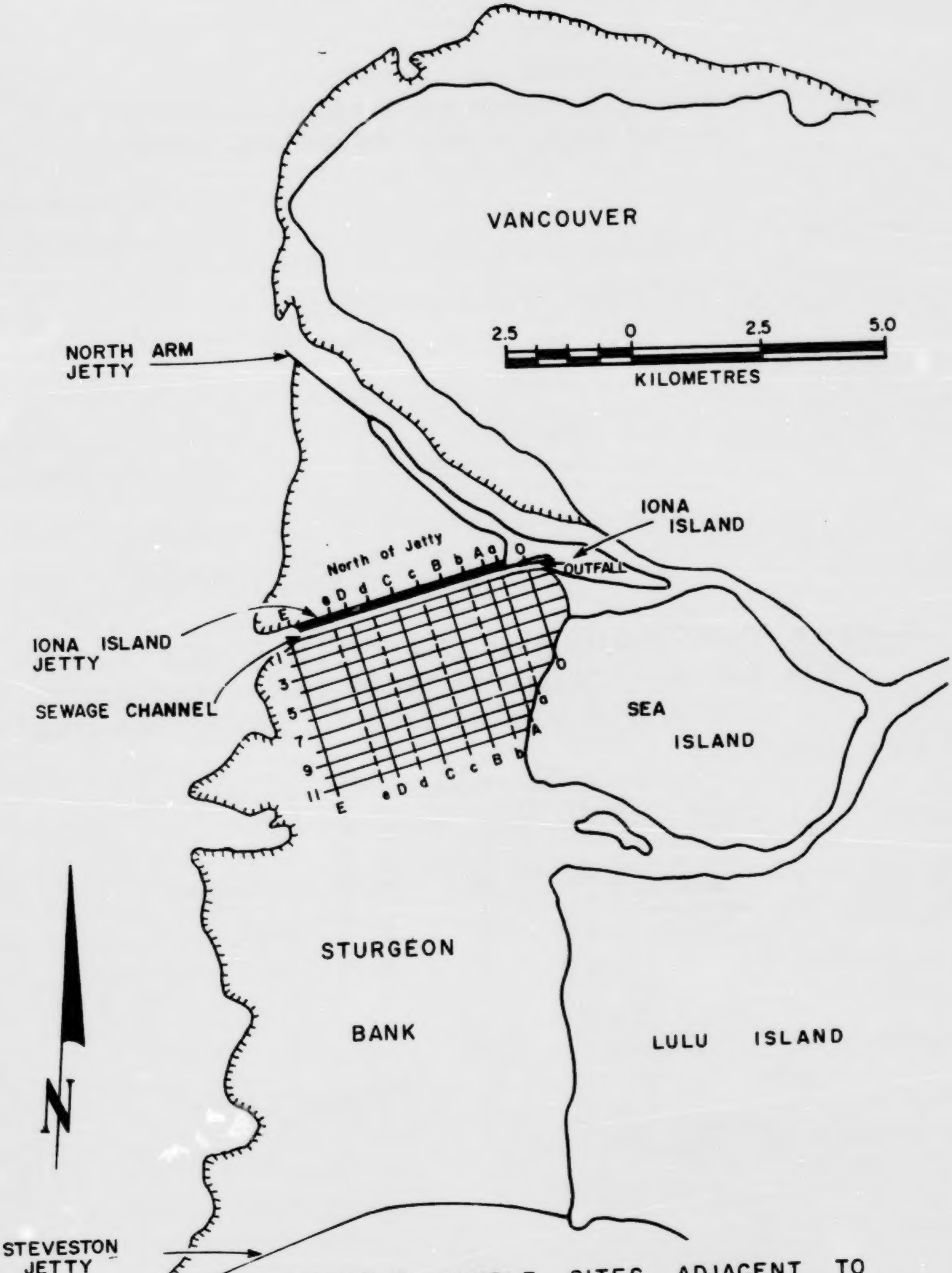

VANCOUVER
2.5
0
2.5
5.0
KILOMETRES
NORTH ARM JETTY
IONA ISLAND
North of Jetty
e D d C c B b A a O
OUTFALL
E
IONA ISLAND JETTY
SEWAGE CHANNEL
1
3
5
7
9
11
E e D d C c B b A a O
SEA ISLAND
STURGEON BANK
LULU ISLAND
N
STEVESTON JETTY

FIGURE 10. SAMPLE SITES ADJACENT TO THE IONA ISLAND OUTFALL (B.C. RESEARCH, 1973; 1975; 1977)

FIGURE 11 . PHOSPHORUS (TOTAL mg/L) IN RECEIVING WATERS NEAR THE IONA STP OUTFALL (B.C. RESEARCH, 1973)

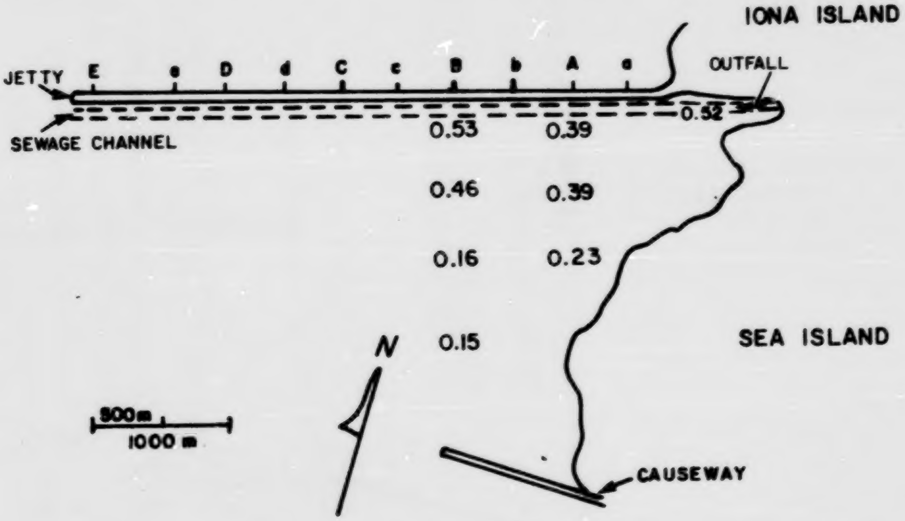

IONA ISLAND
JETTY
E
e
D
d
C
c
B
b
A
a
OUTFALL
0.52
SEWAGE CHANNEL
0.53
0.39
0.46
0.39
0.16
0.23
0.15
N
SEA ISLAND
500m
1000 m
CAUSEWAY

FIGURE 11 a. PHOSPHORUS (TOTAL μg/g dry weight) IN SEDIMENTS TAKEN NEAR THE IONA STP OUTFALL (B.C. RESEARCH 1973; 1975; 1977)

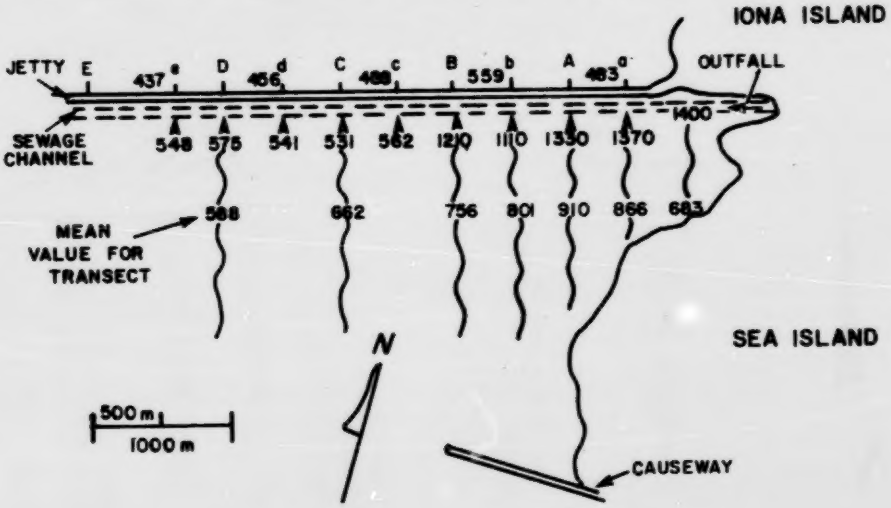

IONA ISLAND
JETTY
E
437
e
D
456
d
C
488
c
B
559
b
A
483
a
OUTFALL
1400
SEWAGE CHANNEL
548
575
541
531
562
1210
1110
1330
1370
MEAN VALUE FOR TRANSECT
588
662
756
801
910
866
683
N
SEA ISLAND
500 m
1000 m
CAUSEWAY

FIGURE 12. LEVELS OF AMMONIA AND NITRATE (mg N/L) IN THE RECEIVING WATERS NEAR THE IONA STP OUTFALL (B.C. RESEARCH, 1973)

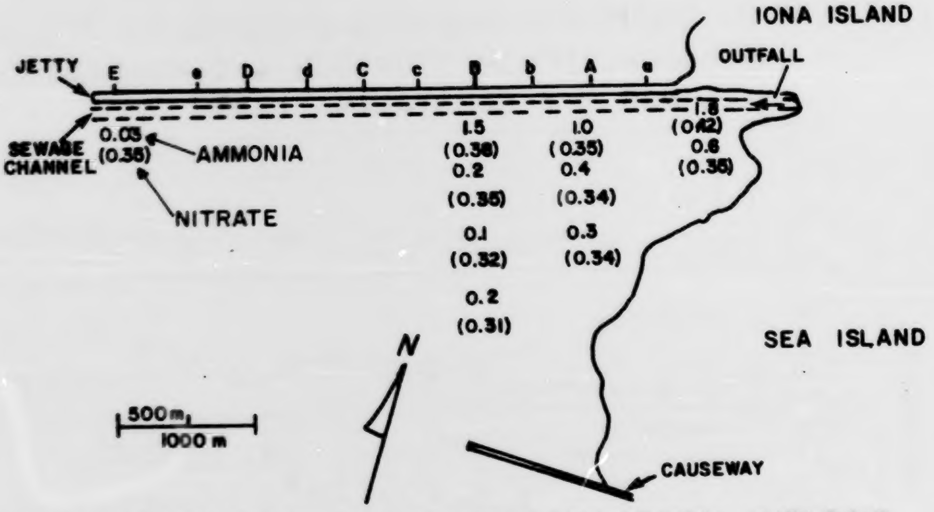

IONA ISLAND
OUTFALL
JETTY
E
e
D
d
C
c
B
b
A
a
SEWAGE CHANNEL
0.03
(0.38)
AMMONIA
NITRATE
1.5
(0.38)
0.2
(0.35)
0.1
(0.32)
0.2
(0.31)
1.0
(0.35)
0.4
(0.34)
0.3
(0.34)
1.8
(0.42)
0.6
(0.38)
N
500m
1000 m
SEA ISLAND
CAUSEWAY

FIGURE 12a. MEAN CONCENTRATIONS OF NITROGEN (TOTAL KJELDAHL µg/g dry weight) IN SEDIMENTS TAKEN NEAR THE IONA STP OUTFALL (B.C.RESEARCH, 1973; 1975; 1977)

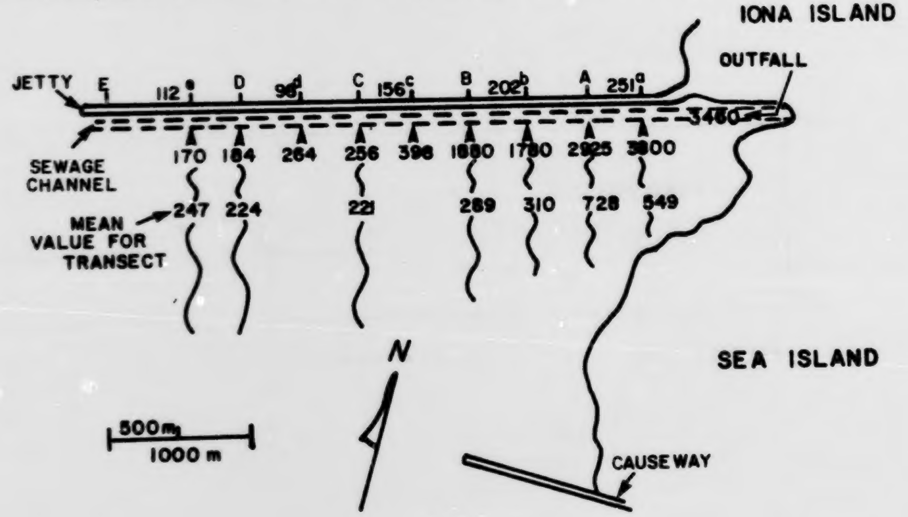

IONA ISLAND
OUTFALL
JETTY
E
112
e
D
98
d
C
156
c
B
202
b
A
251
a
3460
SEWAGE CHANNEL
170
184
264
256
398
1880
1780
2925
3800
MEAN VALUE FOR TRANSECT
247
224
221
289
310
728
549
N
500m
1000 m
SEA ISLAND
CAUSEWAY

FIGURE 13. MACROINVERTEBRATES (NUMBERS OF SPECIES AND INDIVIDUALS) FROM STURGEON AND ROBERTS BANKS (LEVINGS and COUSTALIN, 1975)

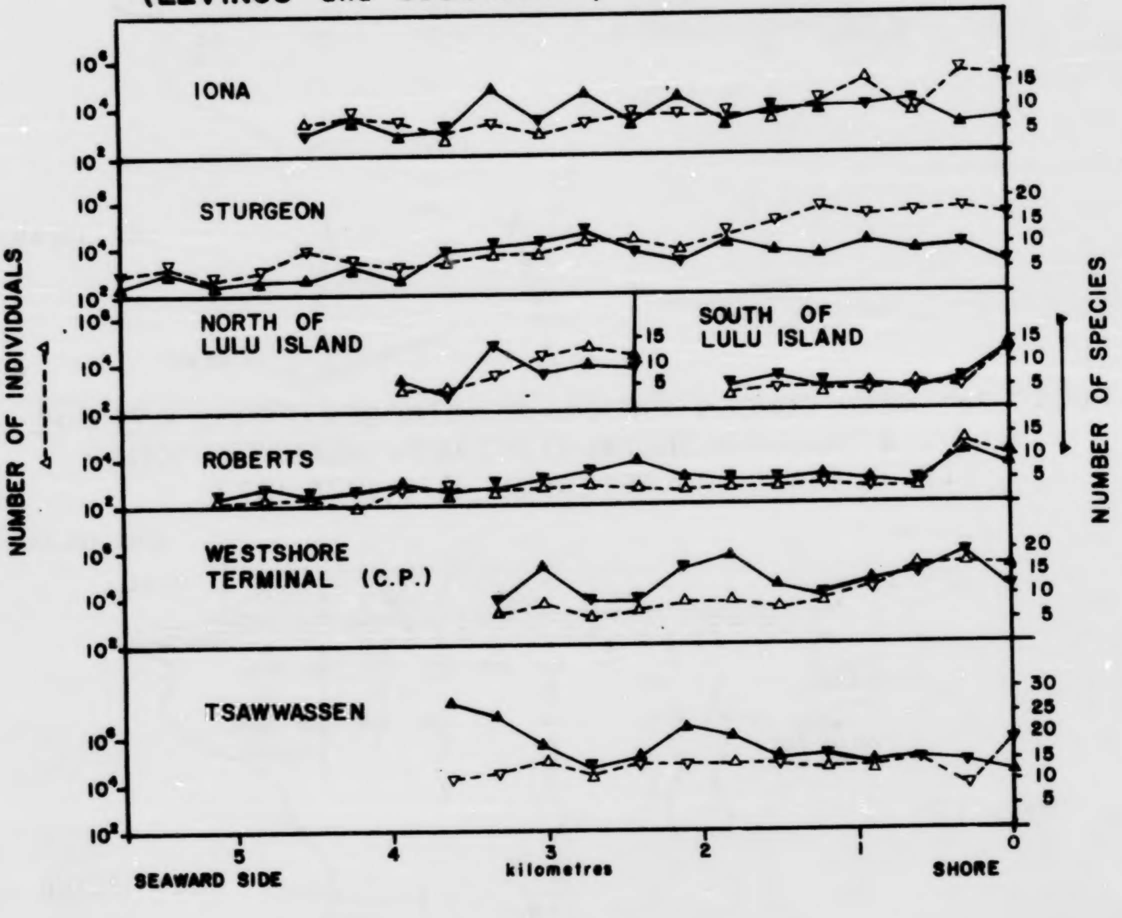
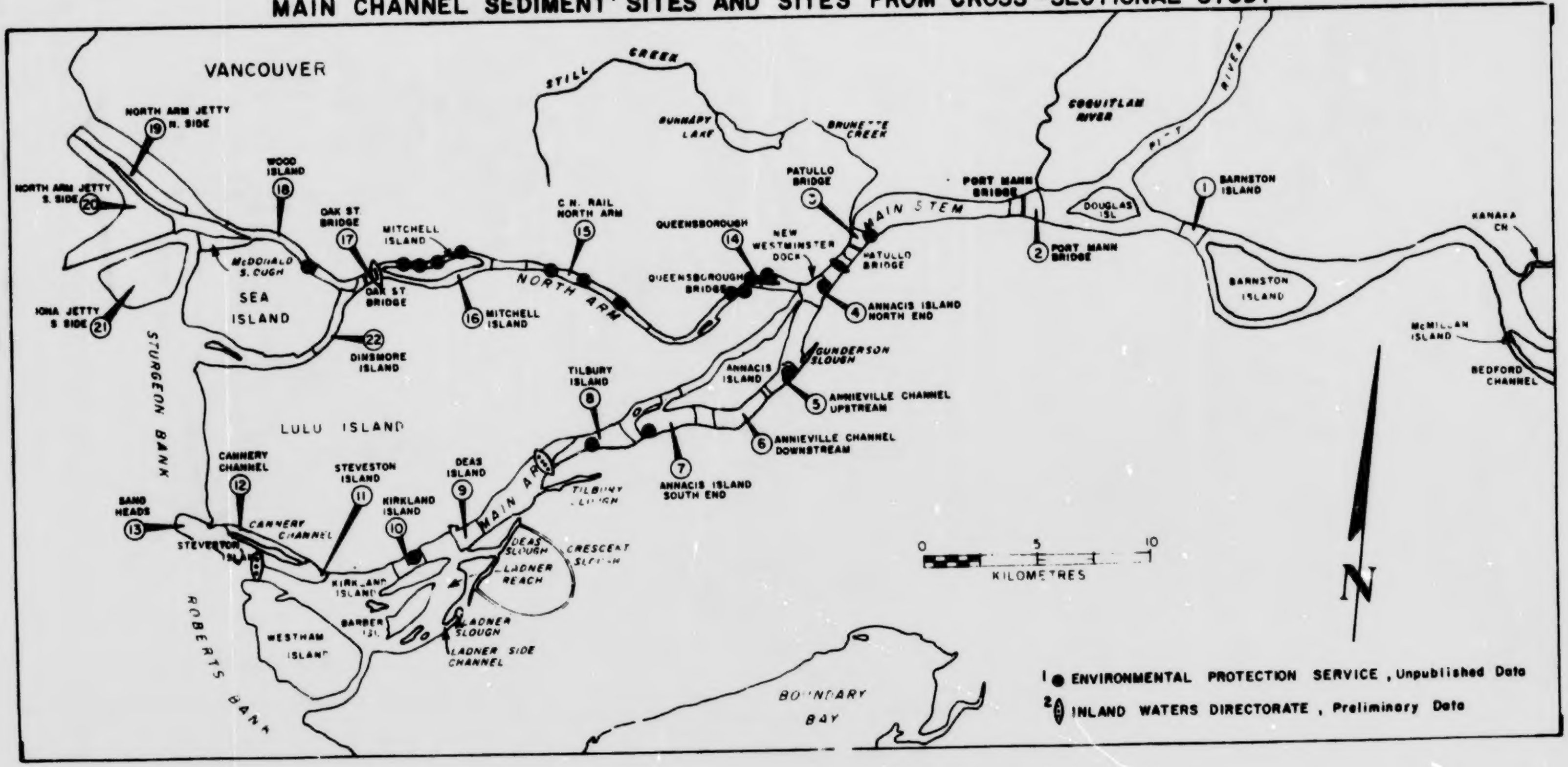


FIGURE 14

MAIN CHANNEL SEDIMENT[1] SITES AND SITES FROM CROSS-SECTIONAL STUDY[2]

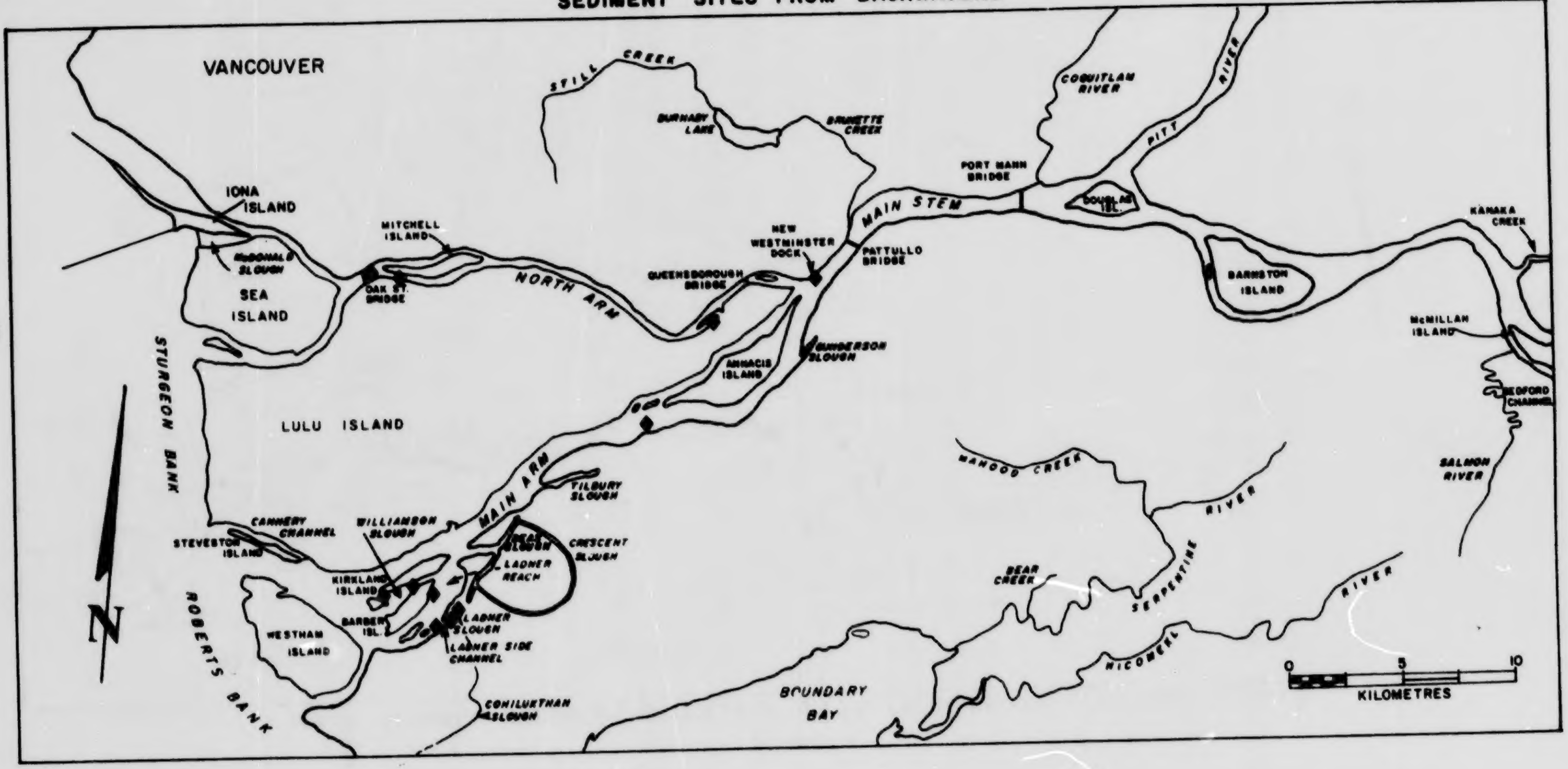

VANCOUVER
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
COQUITLAM RIVER
PITT RIVER
KANAKA CH
McMILLAN ISLAND
BEDFORD CHANNEL
19 NORTH ARM JETTY N. SIDE
20 NORTH ARM JETTY S. SIDE
21 IONA JETTY S SIDE
18 WOOD ISLAND
McDONALD SLOUGH
SEA ISLAND
17 OAK ST. BRIDGE
OAK ST BRIDGE
MITCHELL ISLAND
16 MITCHELL ISLAND
22 DINSMORE ISLAND
15 C.N. RAIL NORTH ARM
NORTH ARM
14 QUEENSBOROUGH
QUEENSBOROUGH BRIDGE
NEW WESTMINSTER DOCK
3 PATULLO BRIDGE
PATULLO BRIDGE
MAIN STEM
PORT MANN BRIDGE
2 PORT MANN BRIDGE
DOUGLAS ISL
1 BARNSTON ISLAND
BARNSTON ISLAND
4 ANNACIS ISLAND NORTH END
GUNDERSON SLOUGH
ANNACIS ISLAND
5 ANNIEVILLE CHANNEL UPSTREAM
6 ANNIEVILLE CHANNEL DOWNSTREAM
7 ANNACIS ISLAND SOUTH END
8 TILBURY ISLAND
TILBURY SLOUGH
LULU ISLAND
STURGEON BANK
9 DEAS ISLAND
MAIN ARM
DEAS SLOUGH
CRESCENT SLOUGH
LADNER REACH
LADNER SLOUGH
LADNER SIDE CHANNEL
10 KIRKLAND ISLAND
11 STEVESTON ISLAND
12 CANNERY CHANNEL
CANNERY CHANNEL
13 SAND HEADS
STEVESTON ISL
KIRKLAND ISLAND
BARBER ISL
WESTHAM ISLAND
ROBERTS BANK
BOUNDARY BAY
0
5
10
KILOMETRES
N

[1] ● ENVIRONMENTAL PROTECTION SERVICE, Unpublished Data

[2] ⬯ INLAND WATERS DIRECTORATE, Preliminary Data

FIGURE 15

SEDIMENT SITES FROM BACKWATERS


VANCOUVER
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
COQUITLAM RIVER
PITT RIVER
PORT MANN BRIDGE
DOUGLAS ISL.
IONA ISLAND
McDONALD SLOUGH
SEA ISLAND
MITCHELL ISLAND
OAK ST. BRIDGE
NORTH ARM
QUEENSBOROUGH BRIDGE
NEW WESTMINSTER DOCK
MAIN STEM
PATTULLO BRIDGE
BARNSTON ISLAND
KANAKA CREEK
McMILLAN ISLAND
BEDFORD CHANNEL
SALMON RIVER
GUNDERSON SLOUGH
ANNACIS ISLAND
LULU ISLAND
STURGEON BANK
MAIN ARM
TILBURY SLOUGH
MAHOOD CREEK
RIVER
CANNERY CHANNEL
WILLIAMSON SLOUGH
STEVESTON ISLAND
DEAS SLOUGH
CRESCENT SLOUGH
LADNER REACH
KIRKLAND ISLAND
BARBER ISL.
LADNER SLOUGH
LADNER SIDE CHANNEL
WESTHAM ISLAND
ROBERTS BANK
CONILUKTHAN SLOUGH
BEAR CREEK
SERPENTINE
NICOMEKL
RIVER
BOUNDARY BAY
N
0
5
10
KILOMETRES

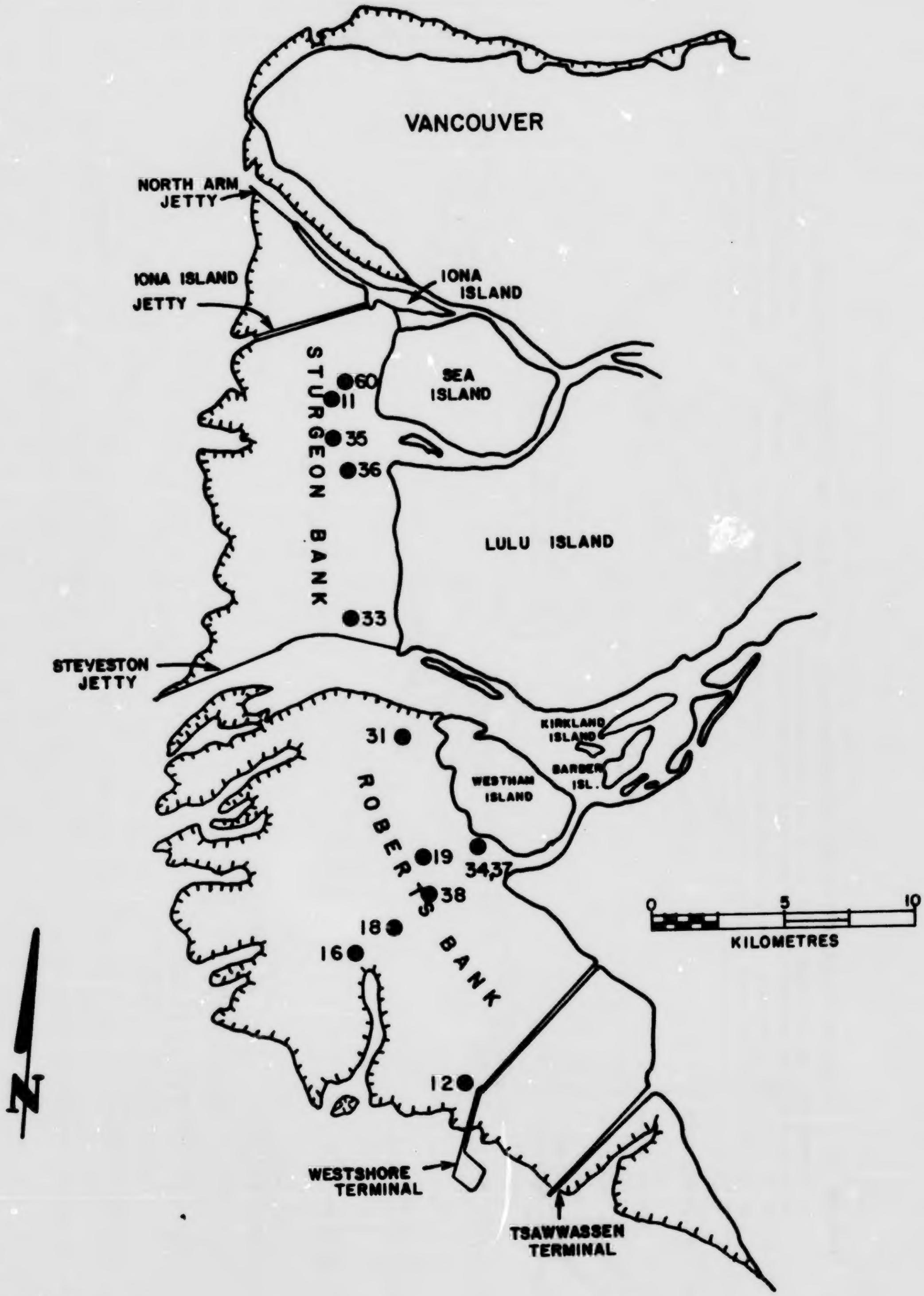
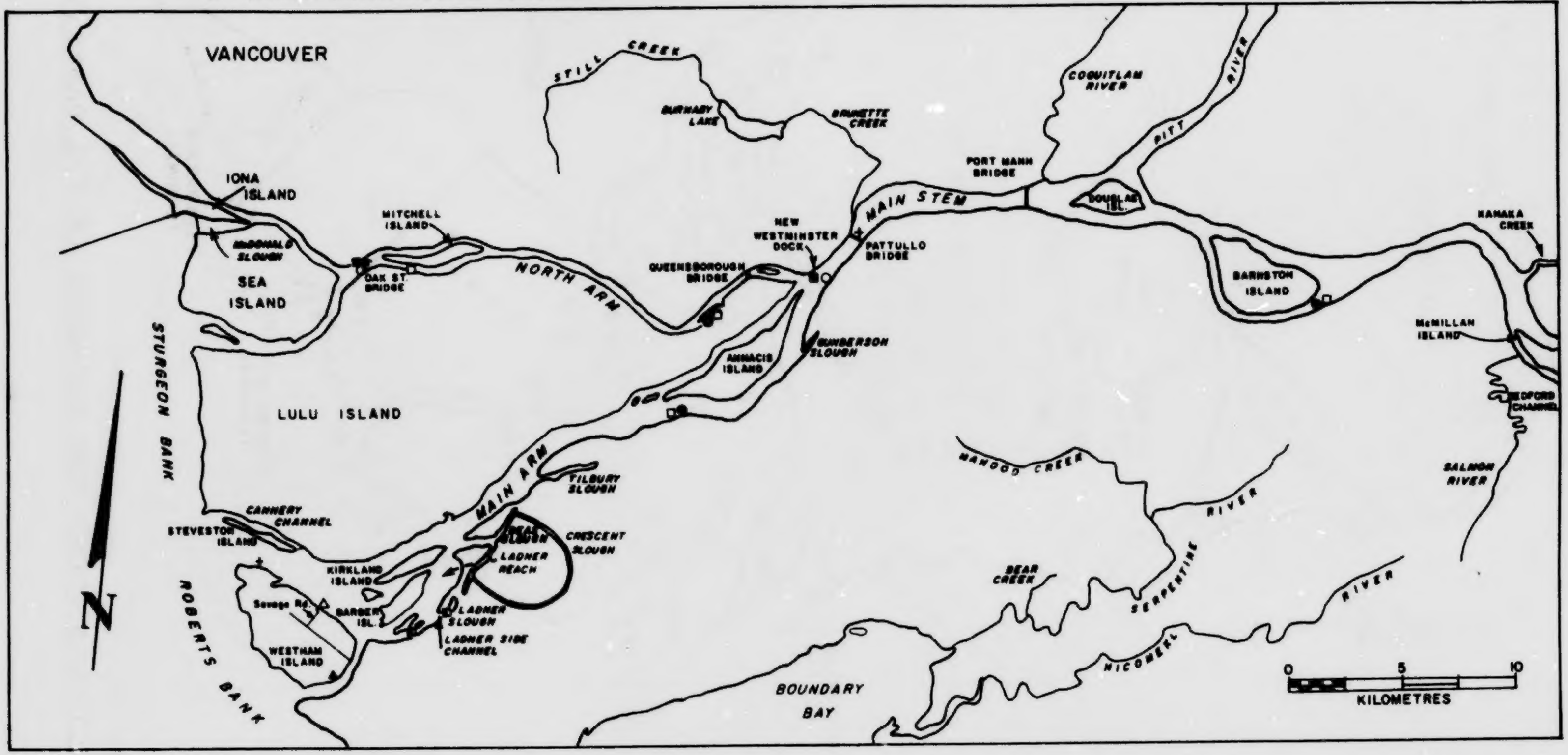

VANCOUVER
NORTH ARM JETTY
IONA ISLAND JETTY
IONA ISLAND
SEA ISLAND
STURGEON BANK
60
11
35
36
LULU ISLAND
33
STEVESTON JETTY
31
KIRKLAND ISLAND
BARBER ISL.
WESTHAM ISLAND
ROBERTS BANK
19
34
37
38
18
16
12
0
5
10
KILOMETRES
N
WESTSHORE TERMINAL
TSAWWASSEN TERMINAL

FIGURE 16
COLLECTION STATIONS FOR SEDIMENTS OF THE BANKS (Fletcher, 1976)

FIGURE 17. SITES OF COLLECTION OF INVERTEBRATES AND ALGAE FOR METALS ANALYSIS

- □ OLIGOCHAETES and CHIRONOMID LARVAE, WATER INVESTIGATIONS BRANCH
- ◧ OLIGOCHAETES and CHIRONOMID LARVAE, WESTWATER RESEARCH CENTRE
- ■ OLIGOCHAETES and CHIRONOMID LARVAE, INLAND WATERS DIRECTORATE
- △ AMPHIPOD COLLECTION, WATER INVESTIGATIONS BRANCH
- ▲ AMPHIPOD COLLECTIONS, INLAND WATERS DIRECTORATE
- ● AMMOCOETES LARVAE, WATER INVESTIGATIONS BRANCH
- ○ AMMOCOETES LARVAE, INLAND WATERS DIRECTORATE
- + ALGAL COLLECTIONS, INLAND WATERS DIRECTORATE


VANCOUVER
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
COQUITLAM RIVER
PITT RIVER
PORT MANN BRIDGE
DOUGLAS ISL.
KANAKA CREEK
IONA ISLAND
MITCHELL ISLAND
McDONALD SLOUGH
SEA ISLAND
OAK ST. BRIDGE
NORTH ARM
NEW WESTMINSTER DOCK
MAIN STEM
PATTULLO BRIDGE
QUEENSBOROUGH BRIDGE
BARNSTON ISLAND
McMILLAN ISLAND
GUNDERSON SLOUGH
ANNACIS ISLAND
BEDFORD CHANNEL
STURGEON BANK
LULU ISLAND
MAIN ARM
TILBURY SLOUGH
NAHOOD CREEK
SALMON RIVER
CANNERY CHANNEL
STEVESTON ISLAND
DEAS SLOUGH
CRESCENT SLOUGH
LADNER REACH
KIRKLAND ISLAND
Savage Rd.
BARBER ISL.
LADNER SLOUGH
LADNER SIDE CHANNEL
WESTHAM ISLAND
ROBERTS BANK
BEAR CREEK
SERPENTINE RIVER
NICOMEKL RIVER
BOUNDARY BAY
N
0
5
10
KILOMETRES

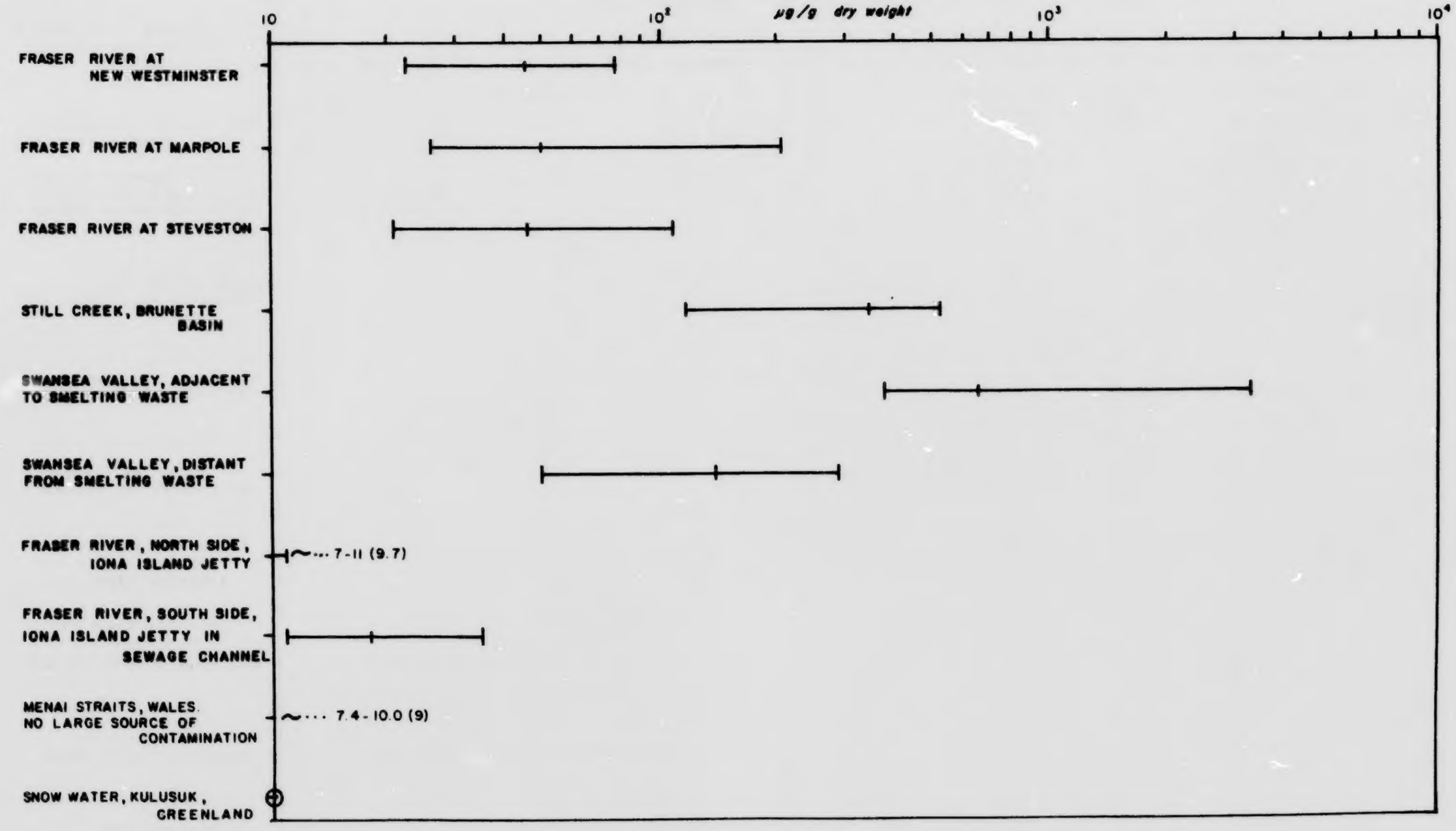


FIGURE 18 . MEAN, MAXIMUM AND MINIMUM VALUES FOR CONCENTRATIONS OF COPPER IN ALGAE FROM VARIOUS LOCATIONS

REFER TO TABLES 3-17 and 3-18 , and SECTION 3.3.3.1 of TEXT

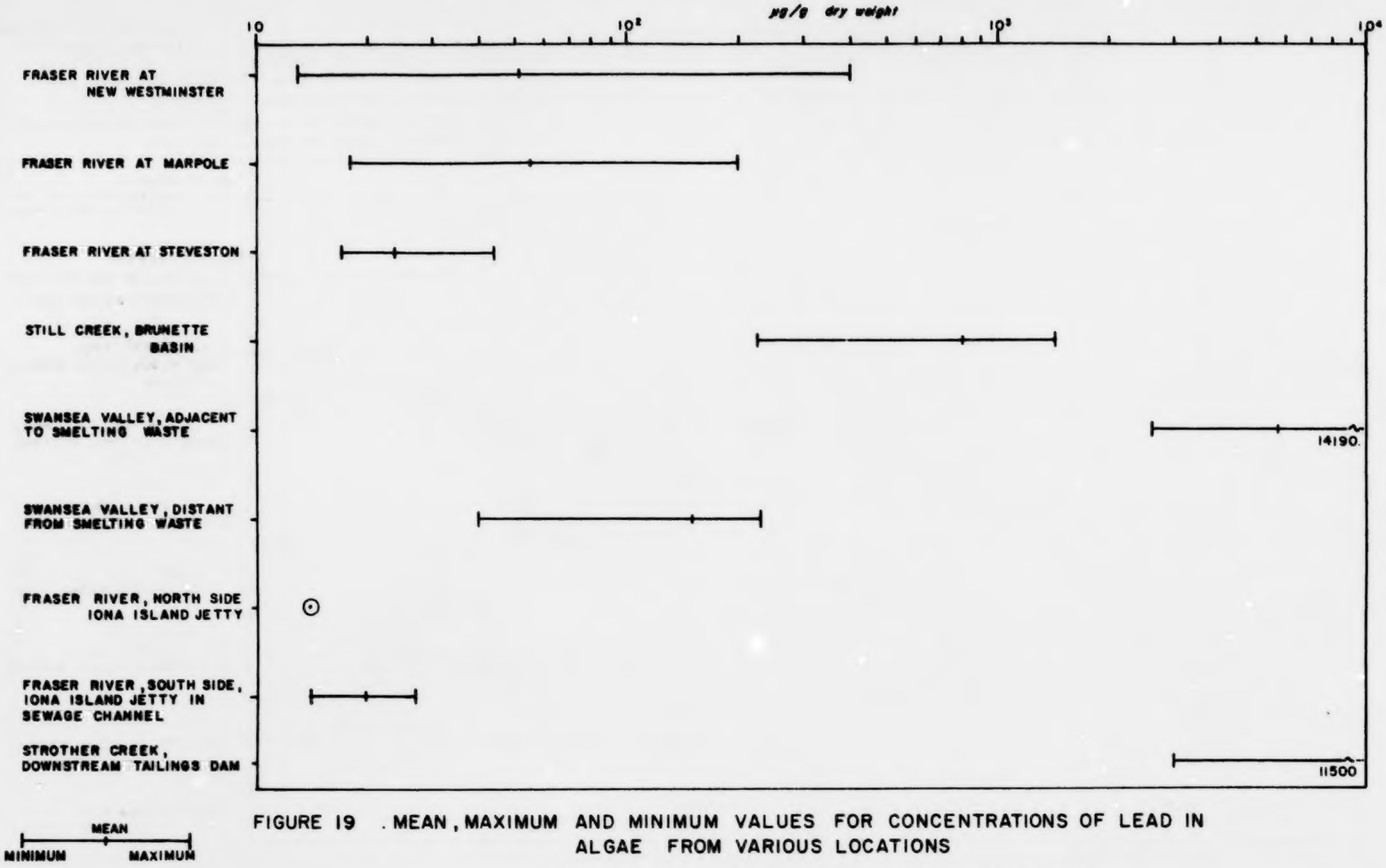


FIGURE 19 . MEAN, MAXIMUM AND MINIMUM VALUES FOR CONCENTRATIONS OF LEAD IN ALGAE FROM VARIOUS LOCATIONS

REFER TO TABLES 3-17 and 3-18, and SECTION 3.3.3.1 of TEXT

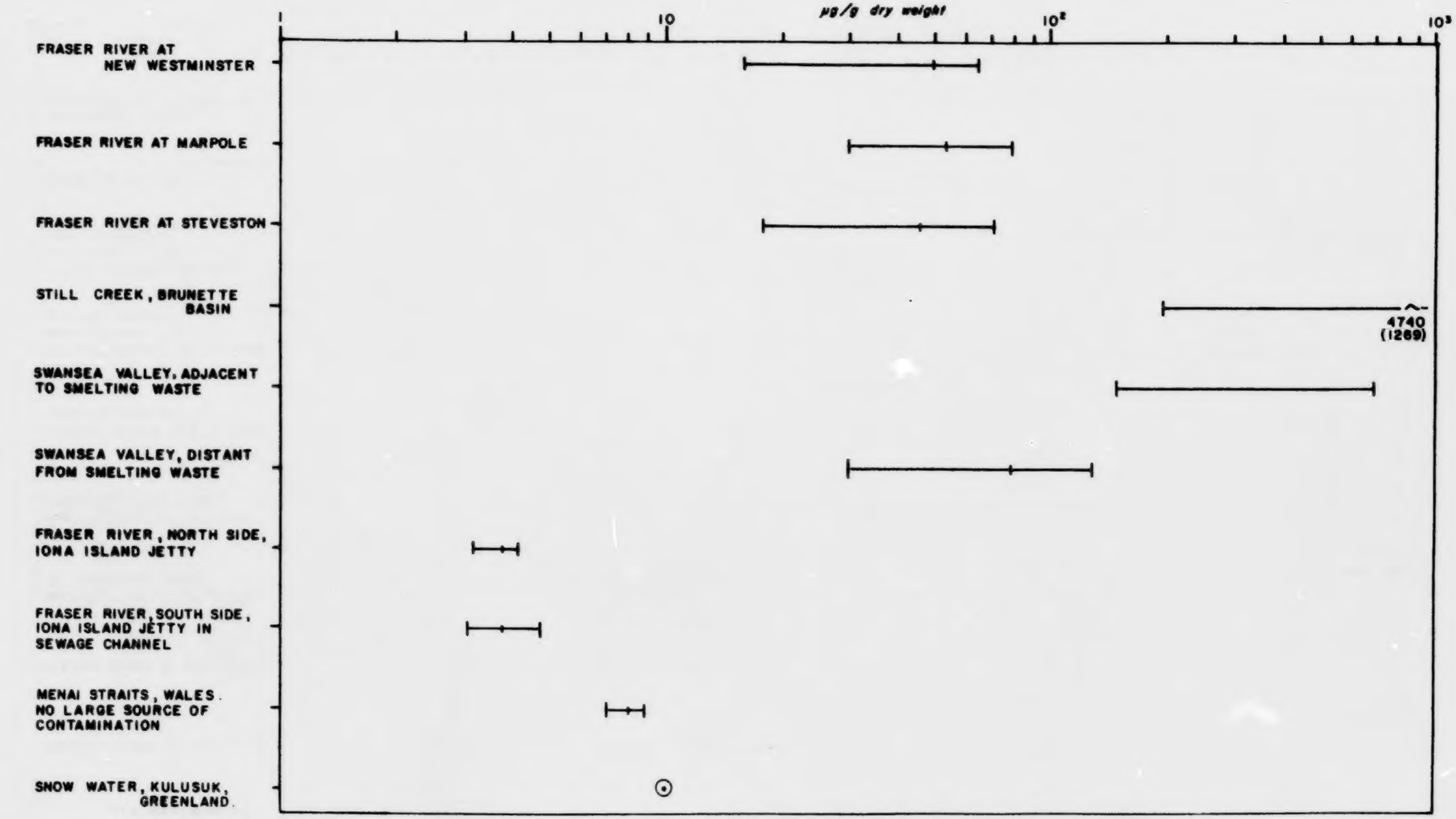


FIGURE 20 . MEAN, MAXIMUM AND MINIMUM VALUES FOR CONCENTRATIONS OF NICKEL IN ALGAE FROM VARIOUS LOCATIONS

REFER TO TABLES 3-17 and 3-18, and SECTION 3.3.3.1 of TEXT

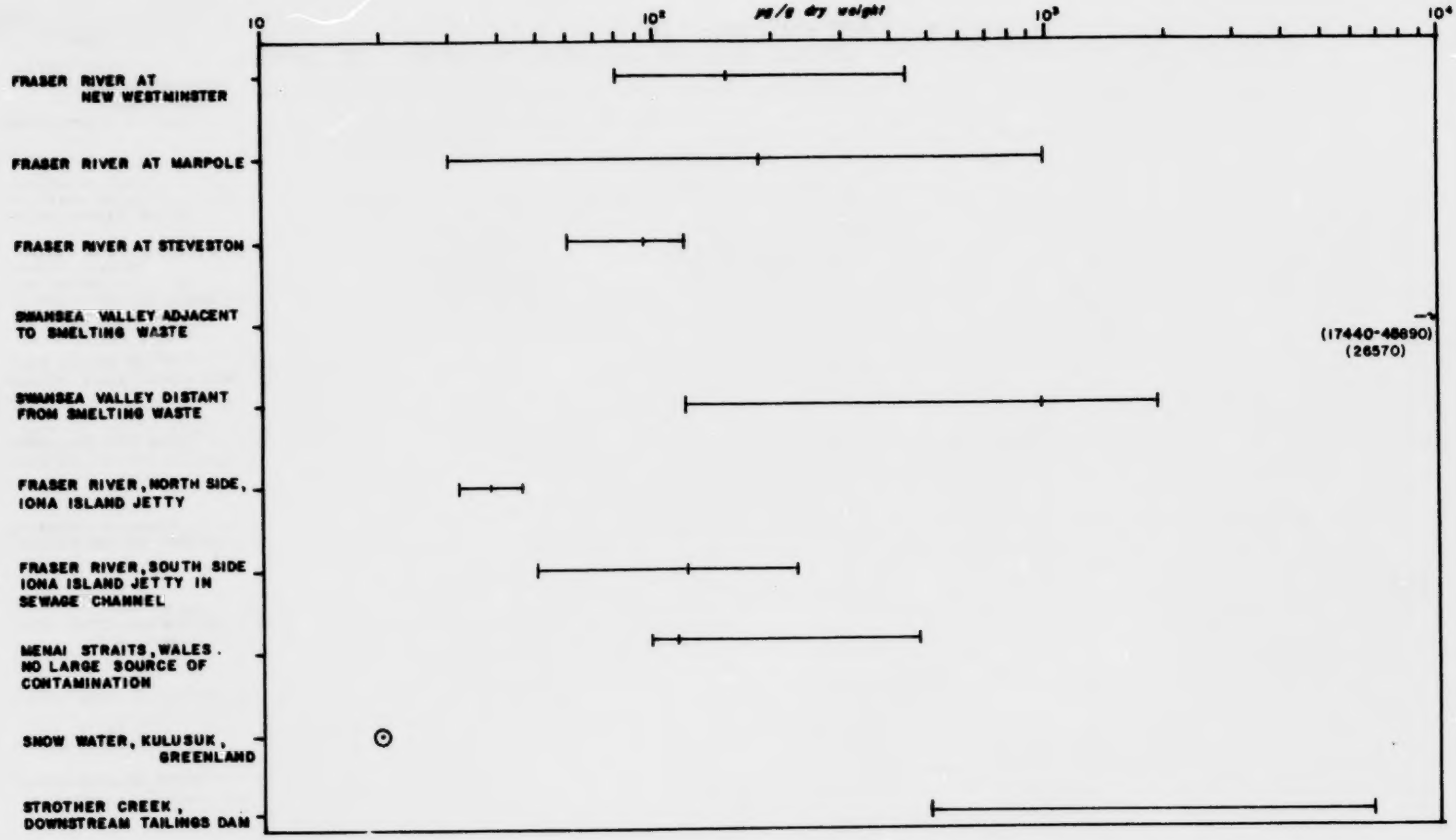


FIGURE 21 . MEAN, MAXIMUM AND MINIMUM VALUES FOR CONCENTRATIONS OF ZINC IN ALGAE FROM VARIOUS LOCATIONS

REFER TO TABLES 3-17 and 3-18, and SECTION 3.3.3.1 of TEXT

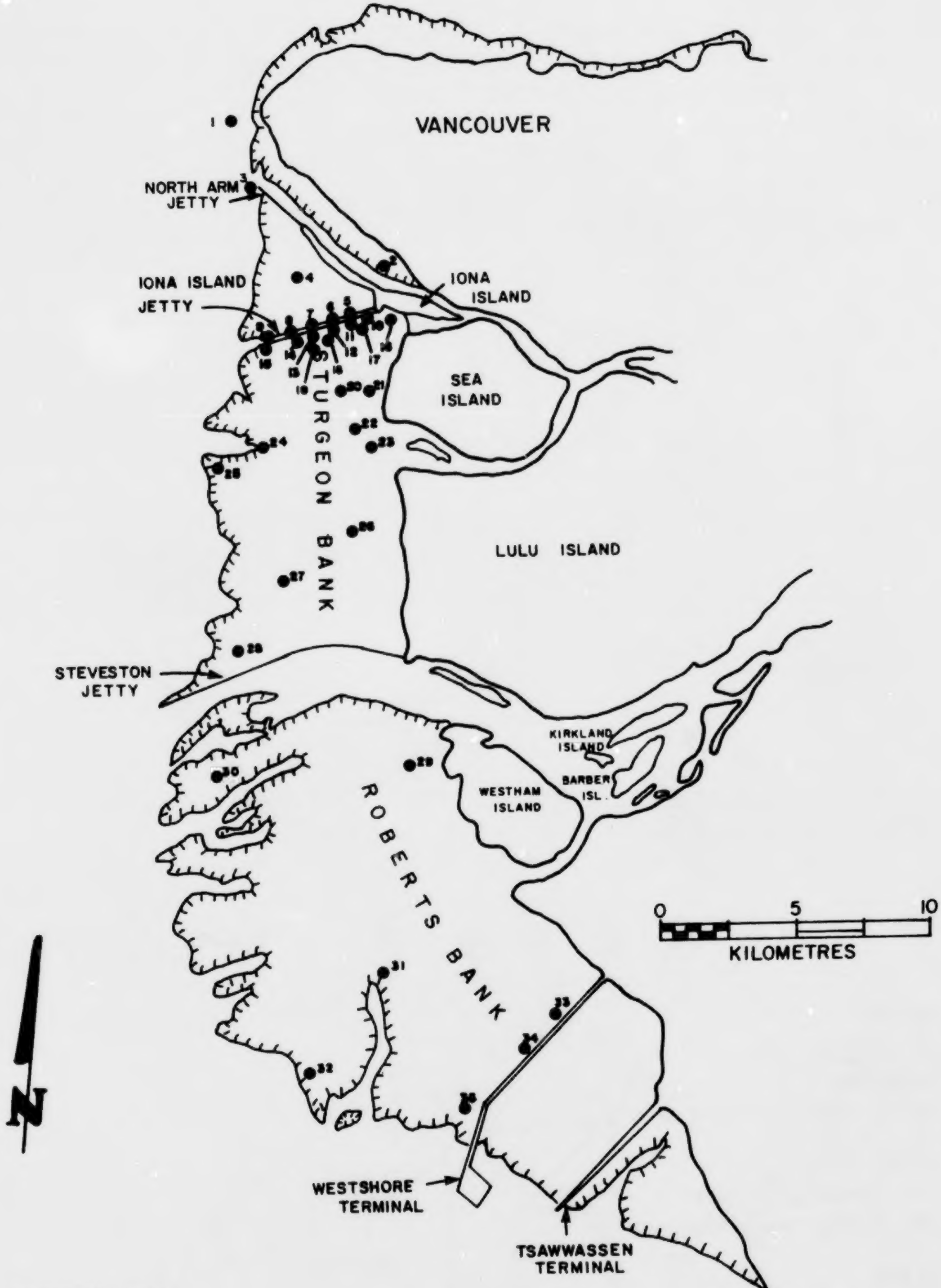

VANCOUVER
NORTH ARM JETTY
IONA ISLAND JETTY
IONA ISLAND
SEA ISLAND
TURGEON BANK
LULU ISLAND
STEVESTON JETTY
KIRKLAND ISLAND
BARBER ISL.
WESTHAM ISLAND
ROBERTS BANK
WESTSHORE TERMINAL
TSAWWASSEN TERMINAL
0
5
10
KILOMETRES
N
1
2
3
4
5
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35

FIGURE 22
COLLECTION STATIONS FOR BIVALVES (DeMill , pers. comm.)

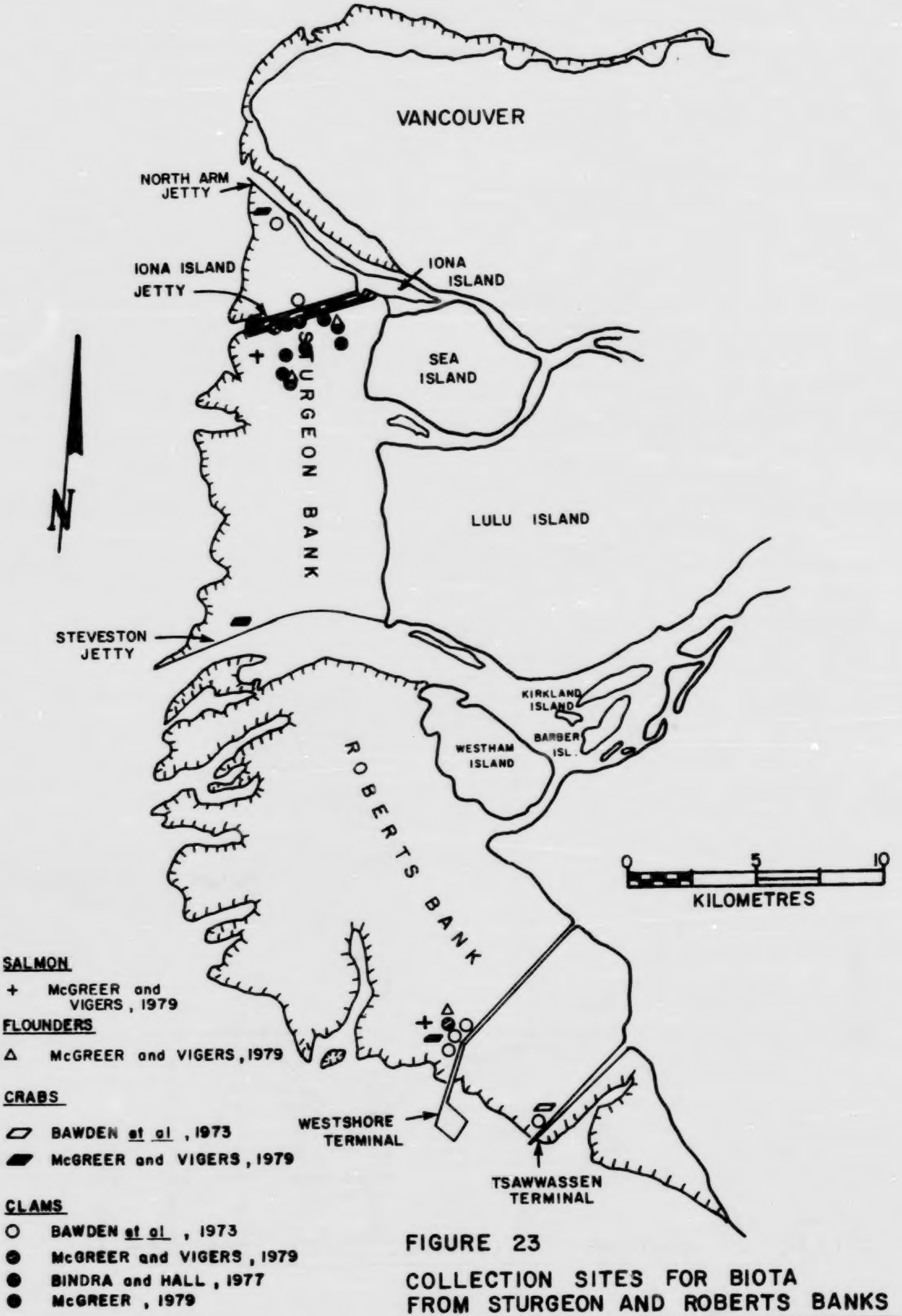
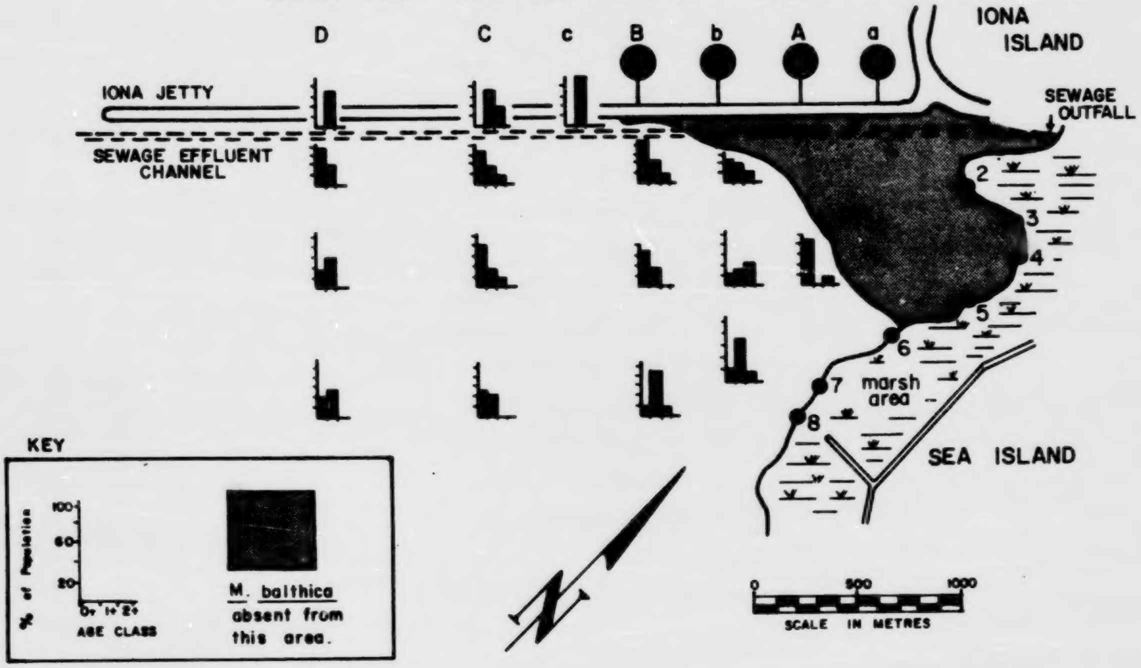

VANCOUVER
NORTH ARM JETTY
IONA ISLAND JETTY
IONA ISLAND
SEA ISLAND
STURGEON BANK
N
LULU ISLAND
STEVESTON JETTY
KIRKLAND ISLAND
BARBER ISL.
WESTHAM ISLAND
ROBERTS BANK
0
5
10
KILOMETRES
WESTSHORE TERMINAL
TSAWWASSEN TERMINAL
SALMON
+ McGREER and VIGERS, 1979
FLOUNDERS
△ McGREER and VIGERS, 1979
CRABS
▱ BAWDEN et al, 1973
▰ McGREER and VIGERS, 1979
CLAMS
○ BAWDEN et al, 1973
● McGREER and VIGERS, 1979
● BINDRA and HALL, 1977
● McGREER, 1979

FIGURE 23

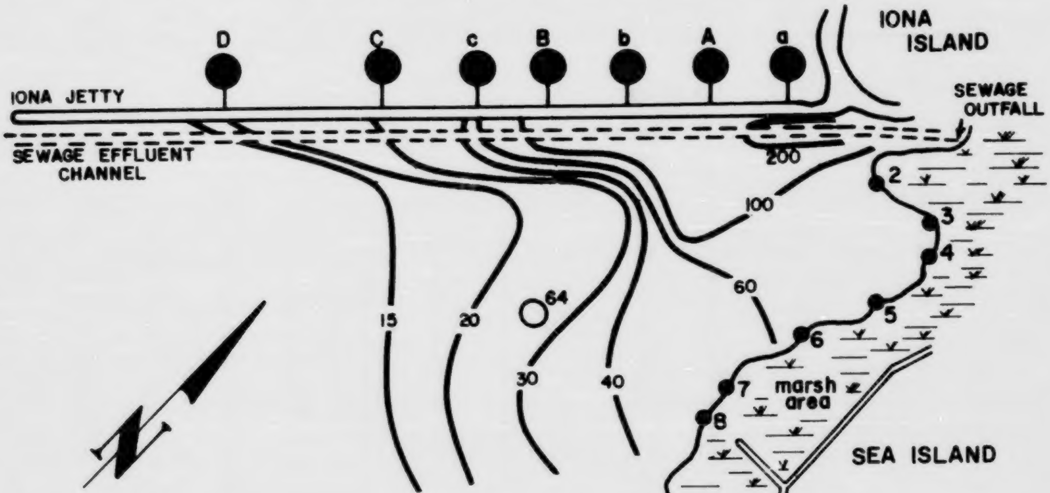
COLLECTION SITES FOR BIOTA FROM STURGEON AND ROBERTS BANKS

FIGURE 24 . AGE CLASS FREQUENCY DISTRIBUTION OF *M. balthica* AT SITES ON STURGEON BANK NEAR THE IONA STP OUTFALL (McGREER,1980)



D
C
c
B
b
A
a
IONA ISLAND
IONA JETTY
SEWAGE OUTFALL
SEWAGE EFFLUENT CHANNEL
2
3
4
5
6
7
8
marsh area
SEA ISLAND
KEY
100
60
20
% of Population
0+ 1+ 2+
AGE CLASS
M. balthica absent from this area.
N
0
500
1000
SCALE IN METRES

FIGURE 24a . DISTRIBUTION PATTERN FOR CONCENTRATION OF COPPER (μg/g) IN SEDIMENTS FROM STURGEON BANK NEAR THE IONA STP OUTFALL (McGREER , 1980)



D
C
c
B
b
A
a
IONA ISLAND
IONA JETTY
SEWAGE OUTFALL
SEWAGE EFFLUENT CHANNEL
200
100
60
15
20
64
30
40
2
3
4
5
6
7
8
marsh area
SEA ISLAND
N
0
500
1000
SCALE IN METRES

KEY TO FIGURE 25 SPECIES ABBREVIATIONS

WS = White Sturgeon
MS = Mountain Whitefish
CT = Cutthroat Trout
RT = Rainbow Trout
DV = Dolly Varden
CA = Carp
PC = Peamouth Chub
NS = Northern Squawfish
RS = Redside Shiner
BS = Bridgelip Sucker
LS = Largescale Sucker
BU = Burbot
PS = Prickly Sculpin

Key to Figures 25-28 Symbols

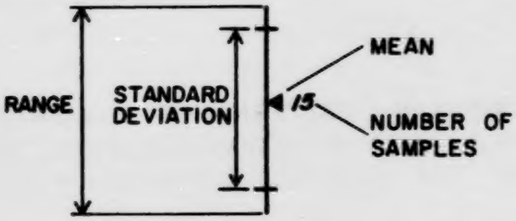

RANGE
STANDARD DEVIATION
MEAN
15
NUMBER OF SAMPLES

FIGURE 25. MEAN (±1 STD. DEV.) AND RANGE OF COPPER, MERCURY AND ZINC LEVELS (μg/g wet weight) FOUND IN MUSCLE TISSUE OF LOWER FRASER R. FISH.

(DRINNAN and NORTHCOTE, In Preparation)

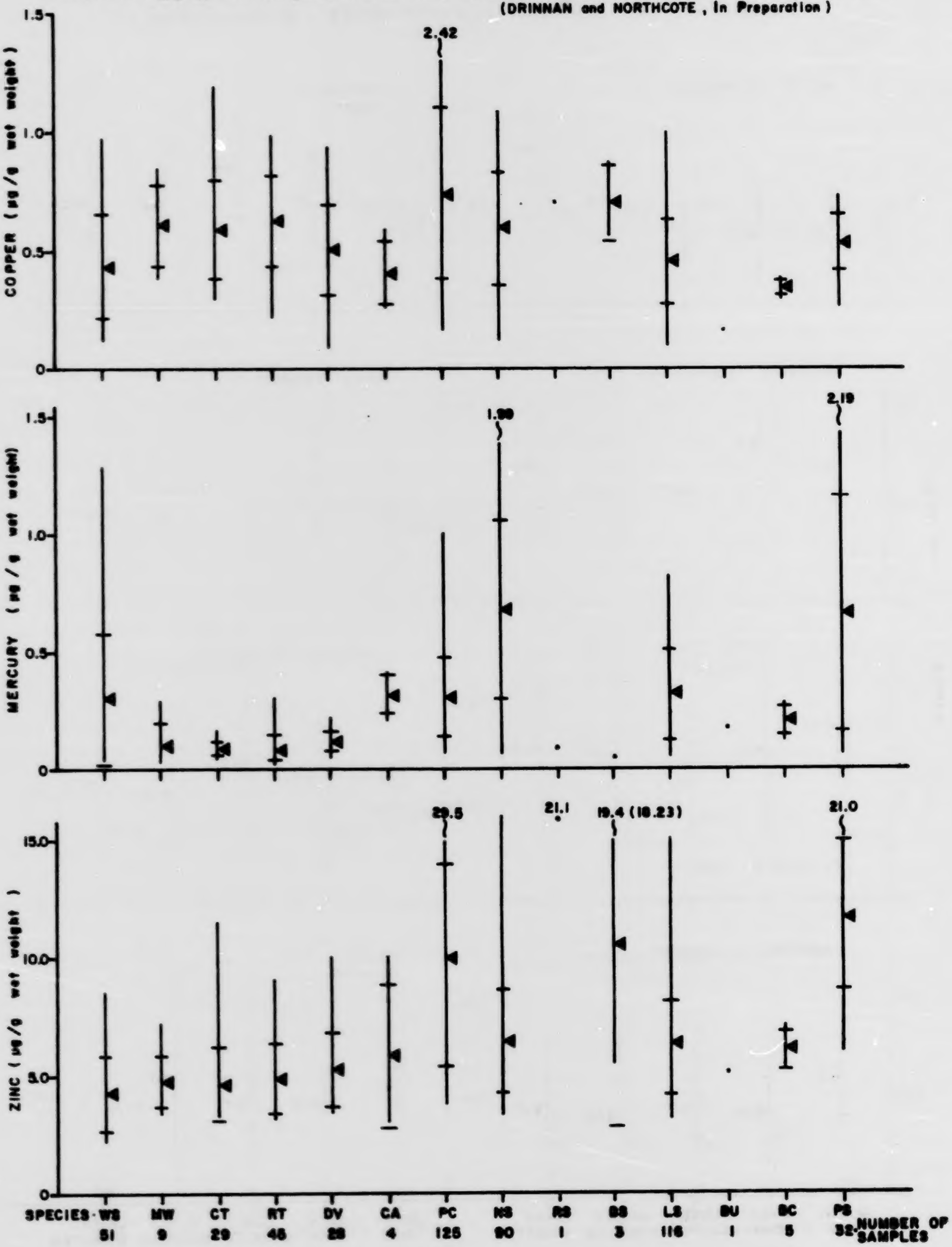


FIGURE 26. CONCENTRATIONS OF COPPER IN EPAXIAL MUSCLE TISSUE OF FISHES FROM DESIGNATED REGIONS OF THE LOWER FRASER RIVER (From DRINNAN and NORTHCOTE , In Preparation)

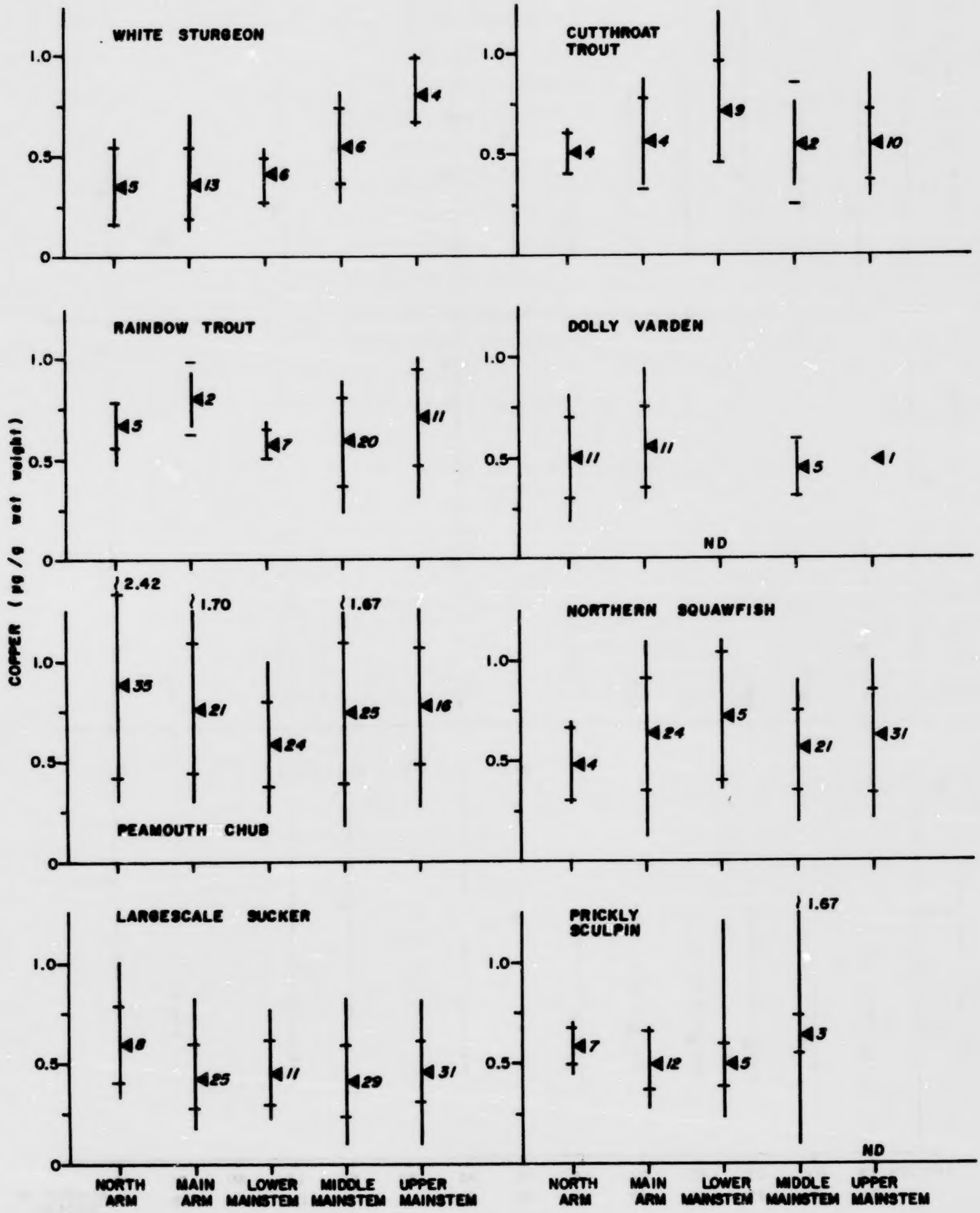


FIGURE 27. CONCENTRATIONS OF MERCURY IN EPAXIAL MUSCLE TISSUE OF FISHES FROM DESIGNATED REGIONS OF THE LOWER FRASER RIVER (From DRINNAN and NORTHCOTE , In Preparation)

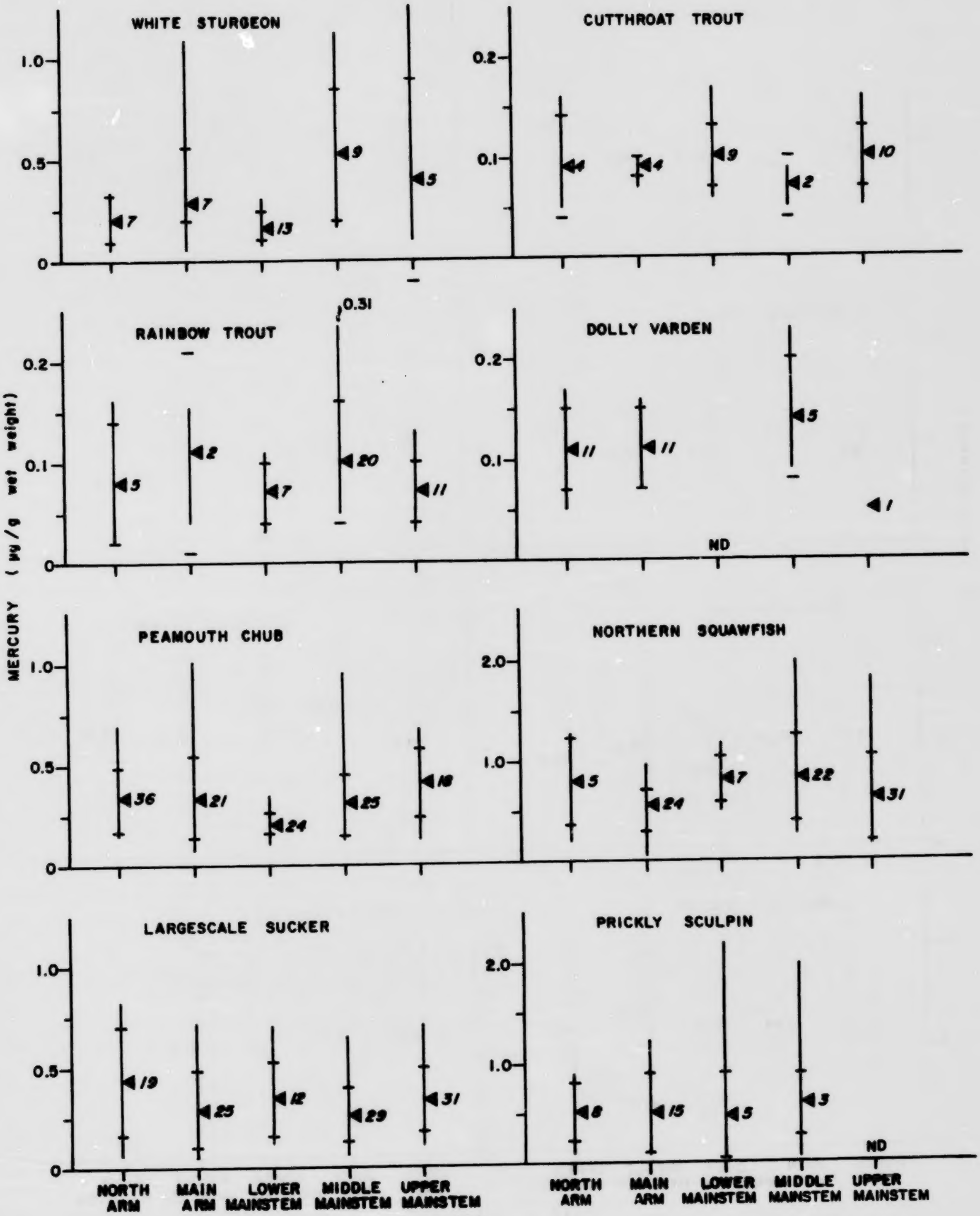


FIGURE 28. CONCENTRATIONS OF ZINC IN EPAXIAL MUSCLE TISSUE OF FISHES FROM DESIGNATED REGIONS OF THE LOWER FRASER RIVER (From DRINNAN and NORTHCOTE , In Preparation)

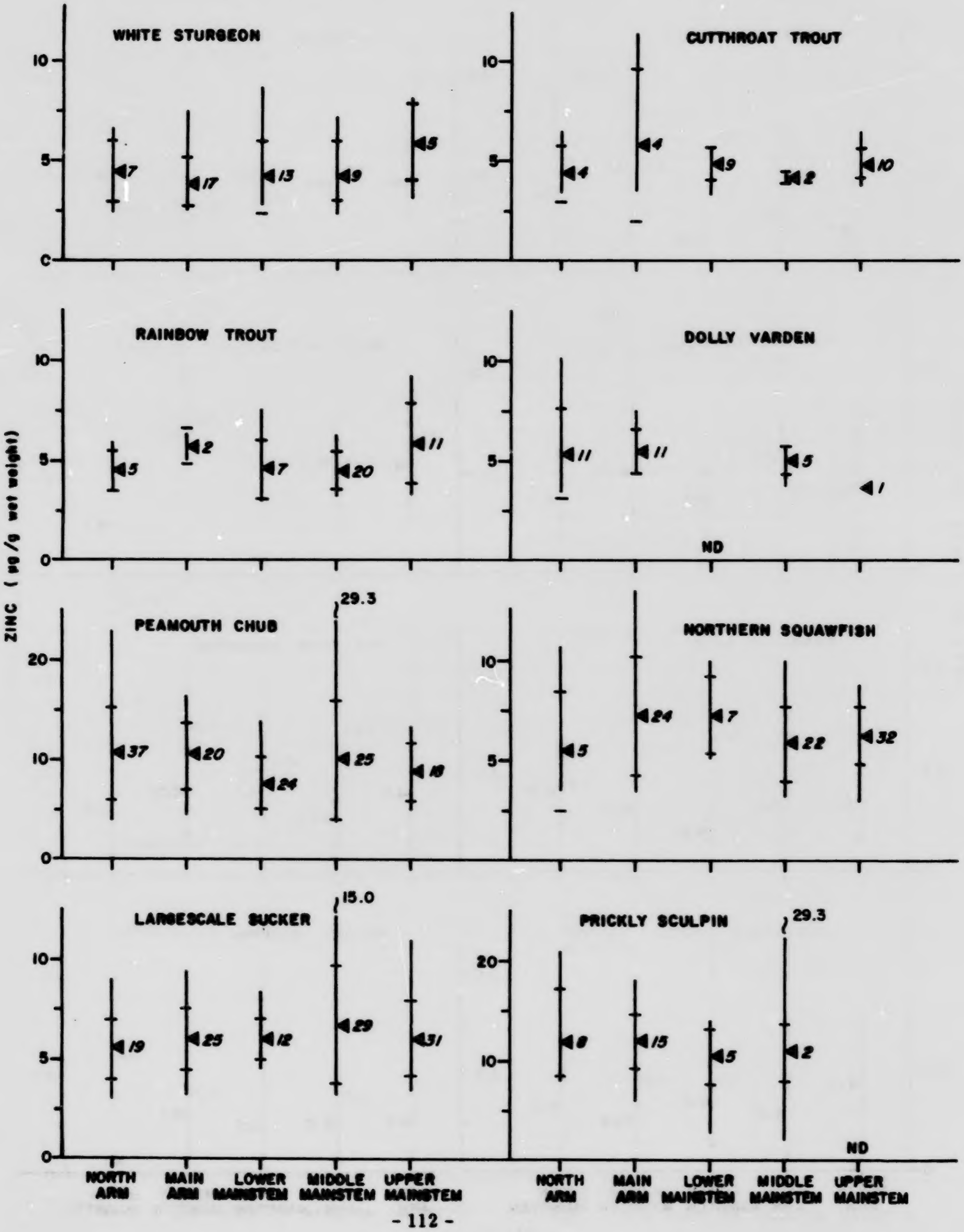
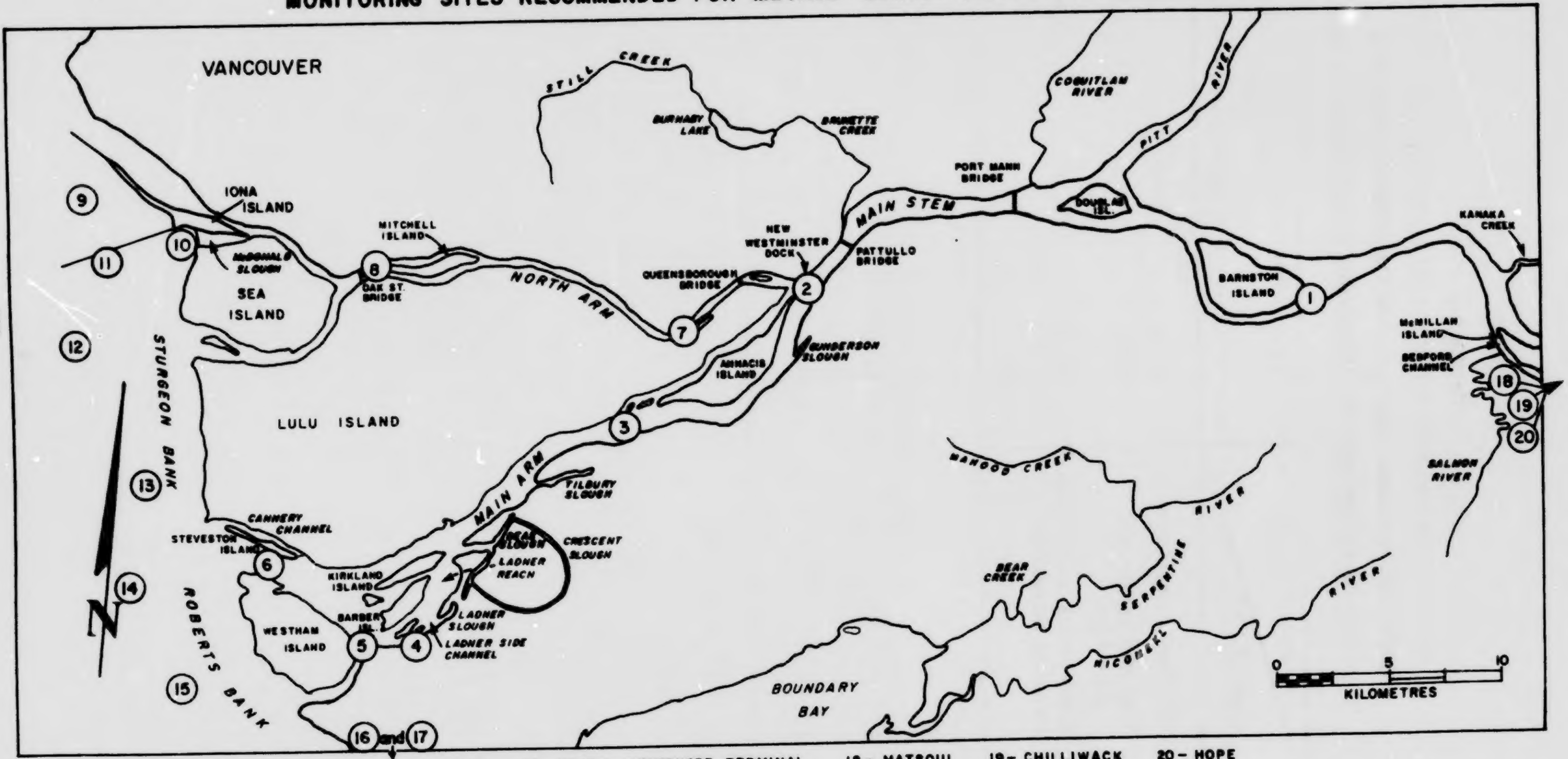


FIGURE 29

MONITORING SITES RECOMMENDED FOR METALS SURVEY (BIOTA AND SEDIMENTS)


VANCOUVER
STILL CREEK
BURNABY LAKE
BRUNETTE CREEK
COQUITLAM RIVER
PITT RIVER
PORT MANN BRIDGE
MAIN STEM
DOUGLAS ISL.
KANAKA CREEK
IONA ISLAND
MCDONALD SLOUGH
SEA ISLAND
MITCHELL ISLAND
OAK ST. BRIDGE
NORTH ARM
QUEENSBOROUGH BRIDGE
NEW WESTMINSTER DOCK
PATTULLO BRIDGE
BARNSTON ISLAND
McMILLAN ISLAND
BEDFORD CHANNEL
ANNACIS ISLAND
GUNDERSON SLOUGH
LULU ISLAND
STURGEON BANK
MAIN ARM
TILBURY SLOUGH
CRESCENT SLOUGH
DEAS SLOUGH
LADNER REACH
CANNERY CHANNEL
STEVESTON ISLAND
KIRKLAND ISLAND
BARBER ISL.
LADNER SLOUGH
LADNER SIDE CHANNEL
WESTHAM ISLAND
ROBERTS BANK
HOGGS CREEK
BEAR CREEK
SERPENTINE RIVER
NICOMEKL RIVER
SALMON RIVER
BOUNDARY BAY
N
0
5
10
KILOMETRES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
and
17
18
19
20

16 – SOUTH WEST ROBERTS BANK 17 – NORTH WESTSHORE TERMINAL 18 – MATSQUI 19 – CHILLIWACK 20 – HOPE

TABLE 2-1

OXYGEN CRITERIA (mg O_2/L) RECOMMENDED FOR THE SUPPORT OF SALMONIDS IN RECEIVING WATERS (DAVIS, 1975)

Level / Class of Fish	A	B	C
Freshwater Salmonids	7.75	6.00	4.25
Salmonid Larvae and Mature Eggs	9.75	8.00	6.50
Anadromous Marine Fish Including Salmonids	9.00	6.50	4.00

TABLE 2-2

AVERAGES OF INDICES FOR THE BENTHIC FAUNA OF THE LOWER FRASER (NORTHCOTE et al., 1976)

Westwater Site (Figure 3)	Equitability	Shannon-Wiener Diversity
1	0.65	1.40
2	0.61	1.44
5	0.22	0.50
3	0.69	1.29
4	0.65	1.12
6	0.67	1.18
7	0.70	1.42
8	0.82	1.20
9	0.71	1.27

TABLE 2-3

LOADINGS SUMMARY FOR DISCHARGES* TO THE LOWER FRASER RIVER AND BANKS (kg/d)

Parameter	Source	Main-stem	Main Arm	North Arm	Banks	Total
Flow (m^3/d)	Municipal[1] Landfill Leachates	-	-	-	-	-
	Industrial[2] Effluents	98 140	102 410	170 330	N.L.	370 880
	Sewage Treatment[3] Plant Discharges	9 400	187 600	N.L.	387 000	584 000
	Stormwater[4]	577 500	218 400	226 800	27 300	1 050 000
Total Suspended Solids	Municipal Landfill Leachates	-	-	-	-	-
	Industrial Effluents	5 430	29 200	25 410	N.L.	60 040
	Sewage Treatment Plant Discharges	260	12 500	N.L.	18 500	31 260
	Stormwater	-	-	-	-	-
Total Nitrogen	Municipal Landfill Leachates	-	-	-	N.L.	610**
	Industrial Effluents	20	210	40	N.L.	270
	Sewage Treatment Plant Discharges (Kjeldahl nitrogen)	100	4 200	N.L.	5 250	9 550
	Stormwater	1 265	475	500	60	2 300

[1] Information taken from Atwater (1980).

[2] Information calculated from Swain (1980).

[3] Information taken from Cain and Swain (1980); based on 1977 data.

[4] Information calculated from Ferguson and Hall (1979).

* No data available for combined sewer overflows or bypasses at the Iona Island STP.

** Loading calculated assuming that ammonia accounts for approximately 90% of the total N loading (J.W. Atwater, personal communication).

- No data.

N.L. No known loading or loading <1.0 kg/d.

TABLE 2-3 (CONTINUED)

LOADINGS SUMMARY FOR DISCHARGES* TO THE LOWER FRASER RIVER AND BANKS (kg/d)

Parameter	Source	Main-stem	Main Arm	North Arm	Banks	Total
Total Phosphorus	Municipal Landfill Leachates (total phosphate)	-	-	-	N.L.	>0.70***
	Industrial Effluents	3.0	22.0	4.0	N.L.	29.0
	Sewage Treatment Plant Discharges	48.0	810.0	N.L.	970.0	1 828
	Stormwater	267	101	105	13	486
BOD_5	Municipal Landfill Leachates	-	-	-	-	-
	Industrial Effluents	835	17 700	5 320	N.L.	23 855
	Sewage Treatment Plant Discharges	280	24 800	N.L.	41 000	66 080
	Stormwater	8 140	3 078	3 197	385	14 800

* No data available for combined sewer overflows or bypasses at the Iona Island STP.
*** No data for Braid St., Leeder, Burns Bog or Richmond Landfills.
- No data.
N.D. No known loading or loading <1.0 kg/d.

TABLE 2-4

SURVEY OF DISSOLVED OXYGEN IN THE LOWER FRASER RIVER, APRIL, AUGUST, OCTOBER, 1978 (ALEXANDER AND BERGERUD, IN PREP.)

Site	Total No. of Measurements	Minimum Value % Saturation	Temperature °C	Minimum Value mg/L	No. of Values <7.75 mg/L
BACKWATERS					
Cannery Channel	96	29.5	13.5	2.70	11
Ladner Slough and Side Channel	64	73.5	11.0	7.35	4
*Deas Slough	79	5.7	6.5	0.65	11
*Tilbury Slough	11	59.2	7.5	7.00	3
Annacis Channel	19	95.4	16.5	9.30	-
Woodward Landing	10	88.2	6.5	9.00	-
Gilmour Slough	19	93.3	17.0	9.00	-
Ewen Slough	18	80.8	17.0	7.80	-
Slough Near Queensborough Bridge	6	87.2	16.5	8.50	-
North Backwater, Mitchell Is.	51	89.7	10.5	9.20	-
Slough D/S Richmond Is.	3	92.3	16.5	9.00	-
Slough Near Richmond Is.	26	86.4	10.5	8.90	-
McDonald Slough	58	16.5	15.5	1.50	10
MAIN CHANNEL					
North of the North Arm Jetty	63	63.6	15.0	6.40	1
Opposite Poplar Is.	22	99.4	16.0	9.60	-
Oak St. Bridge	20	89.1	17.0	8.60	-
Middle Arm	38	91.4	16.0	8.60	-
Opposite Annacis Is.	71	94.3	16.5	9.20	-
Canoe Pass	22	97.4	17.0	9.40	-

* These sites have been studied by the Department of Fisheries and Oceans, Canada, in greater detail. Reports in preparation.

D/S Downstream.

TABLE 2-5

NUTRIENT CONCENTRATIONS IN SELECTED RIVER SYSTEMS OF BRITISH COLUMBIA

Years	Site / Parameter	Total Phosphorus (mg/L)			Total Dissolved Phosphorus (mg/L)			Ortho phosphate P (mg/L)			Nitrogen as Ammonia (mg/L)			Nitrogen as Nitrate (mg/L)		
		Mean	Range	n	Mean	Range	n	Mean	Range	n	Mean	Range	n	Mean	Range	n
1970-1977	Fraser River Lower[1] Mainstem (R3)	0.023	0.005-0.195	90				0.005	0.004-0.013	51	0.010	0.005-0.011	54	0.089	0.022-0.220	59
	Fraser River, Upper North Arm (R 14)	0.045	0.003-0.155	68				0.006	0.004-0.018	55	0.015	0.005-0.050	41	0.102	0.030-0.260	45
	Fraser River, Lower North Arm (R 18, 19)	0.055	0.011-0.115	48				0.059	0.010-0.110	30	0.010	0.005-0.050	24			
	Fraser River, Mid Main Arm (R 6)	0.039	0.004-0.908	166				0.053	0.009-0.530	14	0.020	0.005-3.24	55	0.092	0.024-0.240	107
	Fraser River, Lower Main Arm (R 11, 12, 13)	0.025	0.004-0.205	35				0.028	0.004-0.691	86	0.040	0.005-0.170	22	0.106	0.023-0.225	12
1973-1975	South Thompson River,[2] U/S From Kamloops	0.014	0.006-0.030	18	0.005	<0.003-0.019	17							0.047	<0.020 0.090	17
	Kamloops Lake at Tranquille, D/S From Pulp Mill and STP Lagoons	0.047	0.015-0.172	16	0.020	0.003-0.093	16							0.062	0.030-0.120	16
	Kamloops Lake at Savona	0.007	0.004-0.010	17	0.006	<0.003-0.020	18							0.088	0.040-0.120	16
	South Thompson River, Walhachin	0.011	0.005-0.055	17	0.008	0.004-0.046	15							0.084	0.030-0.130	16
1972-1975	West Kettle River[3], at Grand Forks	0.018	<0.003-0.031	28							0.014	0.005-0.020	20	0.045	<0.020-0.100	20
1975-1976	Upper Elk River[4]	0.008	0.006-0.010	3							0.005	<0.005-0.005	3			
	Elk River Near Mouth	0.050	0.005-0.420	24							0.010	0.005-0.021	24			

[1] Drinnan and Clark, 1980

[2] Thompson River Task Force, Summary Report, 1975

[3] Kootenay Air and Water Quality Study Phase I, 1977.

[4] Kootenay Air and Water Quality Study Phase II, 1978.

n No. of samples.

TABLE 2-6

GENERAL DISTRIBUTION OF ATTACHED ALGAE ALONG THE IONA ISLAND JETTY[1]

Sites / Algae		a	A	b	B	c	C	d	D	e	E
Enteromorpha	sp.	+++	+++	++	+++	+++	++	++	++	++	++
Ulva	sp.	+	++	++	+++	++	+	+	++	+	+
Cladophora	sp.	o	o	o	o	o	o	o	+	+	o
Fucus	sp.	o	o	+	++	++	+++	+++	+	+	++
Porphyra	sp.	o	o	+	+	+	+	+	+	+	+
Lilholhamnia	sp.	o	o	o	o	o	+	o	o	o	+

o	Absent
+	Present
++	Moderately Abundant
+++	Abundant
— — —	Zone of Eutrophication

---

[1] Compiled from data collected by B.C. Research (1973)
Refer to Figure 10 for sample sites.

TABLE 2-7

SALINITY OF INTERSTITIAL WATER IN SEDIMENTS OF THE NORTH ARM OF THE FRASER RIVER AND NORTH OF SEA AND IONA ISLANDS (CHAPMAN, 1979)

Site (Figure 3)	Depth Into Sediment Core (cm.)	Mean Salinity In January, 1978 (ppt)	Mean Salinity In June, 1978 (ppt)
6	0-1	18.5	20.0
	1-2	18.5	20.5
	2-3	18.5	19.0
	3-6	18.5	19.0
5	0-1	18.0	13.0
	1-2	17.0	13.0
	2-3	16.5	13.8
	3-6	16.0	15.0
4	0-1	13.0	4.5
	1-2	13.0	5.0
	2-3	12.0	6.0
	3-6	12.0	6.0
3	0-1	14.0	2.0
	1-2	13.8	3.0
	2-3	13.8	4.7
	3-6	13.0	5.2
2	0-1	7.0	0.5
	1-2	7.0	0.5
	2-3	6.8	1.5
	3-6	6.5	2.0
1	0-1	1.5	0.5
	1-2	1.3	0.5
	2-3	1.1	0.5
	3-6	1.1	0.5

TABLE 2-8

DISTRIBUTION OF TUBIFICIDS IN THE LOWER FRASER RIVER (BRINKHURST, 1979)

Area of River	Wood Island	Dinsmore Island	Steveston Island	Canoe Pass Upstream	Annieville Channel South End	Annacis Island	Pattullo Bridge	Port Mann Bridge	Barnston Island
TUBIFICIDAE									
Limnodrilus									
hoffmeisteri	-	+	+	+	+	+	+	+	+
profundicola	-	-	-	-	+	+	+	-	+
claparedeianus	-	-	-	-	+	-	-	-	-
udekemianus	+	+	+	+	+	-	+	-	+
Tubifex									
tubifex	-	-	+	-	+	-	+	-	-
Ilyodrilus									
frantzi	-	-	-	-	+	+	+	-	-
f. capillatus	-	-	-	-	+	+	-	+	+
mastix	-	+	-	-	+	+	+	+	+
templetoni	-	-	-	-	+	-	-	-	+
Tubificoides									
gabriellae	+	+	-	-	-	-	-	-	-
Paranais									
freyi	-	+	-	-	+	-	-	-	-
Bothrioneurum									
vejdovskyanum	-	+	+	-	-	+	-	-	-
Aulodrilus									
pluriseta	-	+	-	-	+	+	-	-	+
limnobius	-	-	-	-	-	+	-	-	-
Immature Plus Hair Setae	+	+	+	+	+	+	+	+	+
Immature Minus Hair Setae	+	+	+	+	+	+	+	+	+

+	Present
-	Absent

TABLE 2-9

REPORTED FISH KILLS IN TRIBUTARIES TO THE LOWER FRASER RIVER AND IN THE AREA

(DEPT. FISHERIES AND OCEANS, CANADA, UNPUBLISHED DATA)

	Drainage	Mo/Yr	Types of Fish	Number	Cause	Circumstances
Tributaries to the Fraser River	?	5/73	peamouth chub, sturgeon	few	sudden pressure change	?
	A ditch at Port Mann	4/74	cutthroat, stickle back	few	unknown	possibly contamination from lawns or septic tanks
	Creek at Maple Ridge	9/76	coho, trout, sculpin	no data	unknown	?
	McKenny Creek near Kanaka Creek	8/76	trout, coho, lamprey	extensive	unknown	?
	Unnamed creek entering south of Laurentian Linton	8/75	cutthroat, coho	200	unknown	possibly due to draining chlorinated water from a pool to the creek
	Coquitlam River	2/59	juveniles: steelhead, trout, coho	10,000	chlorine	a newly installed municipal pipe was filled with 200,000 gal. of water containing 25 ppm chlorine, then flushed to the ground, exfiltrate to river
	Small tributary stream to Coquitlam River	8/75	trout	numerous	unknown	?
	Brunette Creek	6/70	no data	small	insufficient oxygen	discharge from industry
		6/73	trout, salmon fry	<50	high pH	concrete batch plant discharge
		7/75	chum	no data	unknown	?

TABLE 2-9 (CONTINUED)

REPORTED FISH KILLS IN TRIBUTARIES TO THE LOWER FRASER RIVER AND IN THE AREA

(DEPT. FISHERIES AND OCEANS, CANADA, UNPUBLISHED DATA)

	Drainage	Mo/Yr	Types of Fish	Number	Cause	Circumstances
Other Small Tributaries in Area	Bear Creek Tributary to Serpentine River	4/71	coho, trout	extensive	insecticide suspected	heavy rainfall followed leather jacket spray
		4/72	trout	<50	insufficient oxygen	sewage line repair, release to creek
		4/77	coho, steelhead, cutthroat, lamprey	<100	anionic surfactants	alleged spill of surfactants from foundries
	Mahood Creek Tributary to Serpentine River	4/77	no data	no data	?	?

TABLE 3-1

LOADING SUMMARY OF SELECTED METALS IN DISCHARGES* TO THE LOWER FRASER RIVER AND BANKS (kg/d)

Parameter	Source	Main Stem	Main Arm	North Arm	Sturgeon and Roberts Banks	Total
Total Copper	Municipal Landfill Leachates[1]	0.07	0.11	0.01	N.L.	0.19
	Industrial Discharges[2]	N.L.	0.14	2.10	N.L.	2.24
	Sewage Treatment Plant Discharges[3]	N.L.	25.9	N.L.	78.0	103.9
	Stormwater[4]	10.0	3.5	3.5	1.0	18.0
	TOTAL	10.07	29.65	5.61	79.0	124.33
Total Iron	Municipal Landfill Leachates	112	83.6	4.6	N.L.	200.2
	Industrial Discharges	N.L.	132.5	120.7	N.L.	253.2
	Sewage Treatment Plant Discharges	N.L.	263.0	N.L.	360.0	623.0
	Stormwater	1 110.0	390.0	400.0	100.0	2 000
	TOTAL	1 222	869.1	525.3	460.0	3 076.4
Total Lead	Municipal Landfill Leachates	0.05	0.08	0.03	N.L.	0.16
	Industrial Discharges	N.L.	0.40	6.60	N.L.	7.00
	Sewage Treatment Plant Discharges	N.L.	10.90	N.L.	26.00	36.90
	Stormwater	35.0	13.0	14.0	2.0	64.0
	TOTAL	35.05	24.38	20.63	28.00	108.06

[1] Information taken from Atwater (1980); these are approximate loadings.

[2] Information calculated from Swain (1980).

[3] Information taken from Cain and Swain (1980); based on 1977 data.

[4] Information calculated from Ferguson and Hall (1979).

* No data available for combined sewer overflows or bypasses at the Iona Island STP.

N.L. No known loading or loading insignificant (< 0.05 kg/d).

N.D. Not detectable.

TABLE 3-1 (CONTINUED)

LOADING SUMMARY OF SELECTED METALS IN DISCHARGES* TO THE LOWER FRASER RIVER AND BANKS (kg/d)

Parameter	Source	Main Stem	Main Arm	North Arm	Sturgeon and Roberts Banks	Total
Total Nickel	Municipal Landfill Leachates	0.13	0.04	N.L.	N.L.	0.17
	Industrial Discharges	N.L.	0.01	0.3	N.L.	0.31
	Sewage Treatment Plant Discharges	N.L.	>4.0	N.L.	N.D.	4.0
	Stormwater	3.0	1.0	1.0	1.0	6.0
	TOTAL	3.13	>5.05	1.3	1.0	>10.48
Total Zinc	Municipal Landfill Leachates	0.94	2.13	0.04	N.L.	3.11
	Industrial Discharges	N.L.	0.20	143.0	N.L.	143.20
	Sewage Treatment Plant Discharges	N.L.	40.10	N.L.	44.0	84.10
	Stormwater	21.0	8.0	8.0	1.0	38.00
	TOTAL	21.94	50.43	151.04	45.0	268.41

* No data available for combined sewer overflows or bypasses at the Iona Island STP.

N.L. No known loading or loading insignificant (<0.05 kg/d).

TABLE 3-2

ESTIMATED COPPER, IRON AND ZINC LOADINGS IN THE FRASER RIVER

Sources of Metals	Total Copper		Total Iron		Total Zinc	
	Tonnes/yr	Kg/d	Tonnes/yr	Kg/d	Tonnes/yr	Kg/d
Reach 25;[1] Hope to Mission	420	1 151	1.5×10^5	4.1×10^5	680	1 863
Loadings From[2] Discharges (Storm, Industrial, Municipal, Tributaries)	45	124	1 107	3 076	96	268
Loadings From[3] Discharges Excluding Those to the Banks	16	45	942	2 616	80	223

[1] Drinnan and Clark (1980).

[2] From Table 3-1.

[3] [Loadings from discharges] - [(Loadings from the Iona Island STP, Cain and Swain, 1980) + (Loadings from stormwater; Ferguson and Hall, 1979)].

TABLE 3-3

LOADINGS OF TOTAL METALS TO THE LOWER FRASER FROM LANDFILL LEACHATES (kg/d) (ATWATER, 1980)

Parameter Landfill	Cadmium	Copper	Iron	Lead	Manganese	Nickel	Zinc
Main Stem							
Braid Street[1]	<0.004	0.065	43.0	0.050	3.30	<0.13	0.60
Port Mann[2]	N.C.	N.C.	27.0	N.C.	1.40	N.C.	0.30
Leeder	-	-	40.2	-	1.37	-	-
Terra Nova	-	0.004	<1.30	0.004	0.59	-	0.04
North Arm							
Stride	-	0.004	1.65	-	0.59	-	0.03
Kerr Road	-	0.003	3.00	0.030	0.10	-	0.01
Main Arm							
Burns Bog	N.C.	0.024	16.6	0.035	1.28	0.04	0.83
Richmond Landfill	N.C.	<0.090	67.0	<0.040	22.0	N.C.	1.30

[1] Leachate diverted to the Annacis Island STP since April, 1976.
[2] Leachate diverted to the Annacis Island STP in 1980.
N.C. Loading not calculated because metal below detection limits.
- No data.

TABLE 3-4

SUMMARY OF AGENCIES WHICH HAVE ANALYSED FRASER RIVER SEDIMENTS AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(1) Packman, unpublished data	Environmental Protection Service	Laboratory Services, Pacific Region (EPS-FMS)	1) Freeze Field Collections 2) Freeze-dry Sample 3) Pass Through 150 μm Mesh Sieve and Process Sievate	1) Digest with HCl; HNO_3 2) Heat for 3 Hours 3) Analyse Supernatant with AAS	1) Digest with $HNO_3 + H_2SO_4 + HCl$ 2) Boil 3) Add $K_2S_2O_8$ 4) Filter and Analyse Filtrate with AAS
(2) Chapman et al., 1980 and in preparation	Inland Waters Directorate	Water Quality Branch, Analytical Services Lab	1) Store Field Collections at 4°C 2) Dry Sample at 50°C 3) Pass Through 63 μm Mesh Sieve and Process Sievate	1) Digest with H_2O_2 2) Heat for 2 Hours 3) Digest with HNO_3 4) Heat for 0.5 Hours 5) Analyse Supernatant with AAS	1) Digest with $H_2SO_4 + HNO_3 + HCl$ 2) Let Stand for 2 Hours at 50°C 3) Add $KMnO_4$ 4) Let Stand 30 Minutes 5) Add $K_2S_2O_8$ 6) Let Stand Overnight 7) Add $(NH_3OH)_2SO_4$ 8) Analyse Supernatant
(3) Water Investigations Branch, unpublished data; Appendix I	Water Investigations Branch	Environmental Lab (B.C.) A Lab Manual for the Chemical Analysis of Waters, Wastewaters, Sediments and Biological Tissues	1) Freeze Field Collections 2) Dry Sediments at 105°C (Air Dry for Hg) 3) Pass Through 150 μm Mesh Sieve and Process Sievate	1) Digest with HNO_3; $HClO_4$ 2) Boil for 2 Hours 3) Analyse Supernatant with AAS for PES	1) Digest with $HCl + HNO_3$ 2) Heat 3) Add $KMnO_4$ and K_2SO_4 4) Heat, Cool 5) Add Hydroxylamine Sodium Chloride Solution 6) Add Stannous Chloride 7) Analyse with Flameless AAS

TABLE 3-4 (CONTINUED)

SUMMARY OF AGENCIES WHICH HAVE ANALYSED FRASER RIVER SEDIMENTS AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(4) B.C. Research, 1973; 1975; 1977	B.C. Research	B.C. Research		1) Digest with HNO_3; $HClO_4$ 2) Digest for 8 Hours 3) Analyse Supernatant	1) Digest with HCl, HNO_3 2) Add $KMnO_4$ 3) Heat to 95°C 4) Add Hydroxylamine Sodium Chloride Solution 5) Add Stannous Chloride 6) Analyse
(5) Grieve and Fletcher, 1976	U.B.C., Dept. Geological Sciences	Dept. Geological Sciences	1) Dry Sediments at 70°C for 48 Hours 2) Pass Through 177 μm Mesh Sieve and Process Sievate	1) Digest with HNO_3; $HClO_4$ 2) Treat with $MgCl_2$; NH_2OH-HCl in Acetic Acid; HNO_3-$HClO_4$ or 3) Treat with NH_2OH-HCl in Acetic Acid and HF-HNO_3-$HClO_4$ 4) Analyse Supernatant with AAS	
(6) Fletcher, 1976	U.B.C., Dept. Geological Sciences	Dept. Geological Sciences	As Above (5)	As Above (5)	

TABLE 3-4 (CONTINUED)

SUMMARY OF AGENCIES WHICH HAVE ANALYSED FRASER RIVER SEDIMENTS AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(7) Hall, Yesaki and Chan, 1976	Westwater Research Centre	U.B.C., Dept. Geological Sciences	1) Dry at 110^oC for 48 Hours 2) Pass Through 177 μm Mesh Sieve and Process Sievate	1) Digest with HNO_3; $HClO_4$ 2) Reflux for 1 Hour 3) Analyse Supernatant with AAS	1) Digest with H_2SO_4 2) Let Stand at 50^oC for 5 Hours 3) Oxidize with H_2O_2 at 50^oC 4) Add $KMnO_4$ 5) Reduce with $SnCl_2$-$2H_2O$ 6) Analyse with AAS
(8) Bindra and Hall, 1977	Westwater Research Centre	U.B.C., Environmental Engineering Laboratory	1) Pass Field Collections Through 210 μm Mesh Sieve, Flush With Nitrogen 2) Keep Cool	1) Digest with HNO_3-HF- 2) Add $HClO_4$-HNO_3 3) Add HF 4) Add HCl-HNO_3 5) Analyse	
(9) Hall, 1979	Westwater Research Centre	Westwater Research Centre	As Above (8)	As Above (8)	
(10) Bourque and Adams, 1975	B.C. Research	B.C. Research	As Above (4)	As Above (4)	

TABLE 3-4 (CONTINUED)

SUMMARY OF AGENCIES WHICH HAVE ANALYSED FRASER RIVER SEDIMENTS AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(11) Inland Waters Directorate, preliminary data	Inland Waters Directorate	Water Quality Branch, Analytical Services Lab; I.W.D. Analytical Methods Manual	1) Air Dry (Dry at 105°C for 24 h for Hg) 2) Sieve Two Size Fractions <180 μm and >180; <850 μm	1) Digest with HCl 2) Shake at Room Temp. Overnight 3) Analyse Filtered Solution with AAS	Refer to (2) above; Water Quality Branch, Analytical Services Lab Except Carry Out Extraction on Material Passed Through an 850 μm Sieve

TABLE 3-5

PARTICLE SIZE ANALYSIS OF SEDIMENTS FROM POINTS IN RIVER CROSS-SECTIONS[1]

Site	Location in Cross Section	No. of Samples	Percent Particles in Each Size Class			
			Pebbles (16.0-2.0 mm)	Coarse and Medium Sand (2.0-0.25 mm)	Fine Sand (0.25-0.0625 mm)	Silt and Clay (<0.0625 mm)
Steveston	Near South Bank	1	0	57.5	42.3	0.2
	Midstream	1	0	81.0	18.9	0.1
	Near North Bank	1	0	90.5	9.4	0.1
Tilbury Island	Near South Bank	1	0	3.0	96.0	1.0
	South of Midstream	1	3.0	85.5	11.5	0
	North of Midstream	1	0	96.0	4.0	0
	Near North Bank	1	0	76.5	23.5	0
Oak St. Bridge	Near South Bank	1	0	0.5	7.5	92.0
	South of Midstream	1	0	91.5	9.5	0
	North of Midstream	1	0	97.5	2.5	0
	Near North Bank	1	0	9.5	28.0	62.5
New Westminster	Near South Bank	1	0	7.0	92.5	0.5
	South of Midstream	1	0	23.5	76.5	0
	North of Midstream	1	0	98.5	1.5	0
	Near North Bank	1	1.0	95.5	3.5	0

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[1] Inland Waters Directorate; preliminary data.

TABLE 3-6

METAL CONCENTRATIONS (µg/g Dry Wt.) IN SEDIMENTS FROM THE LOWER FRASER RIVER TAKEN ACROSS THE RIVER CHANNEL. PARTICLE SIZE: >180 µm, <850 µm[1]

Site	Location in Cross-section	Copper Mean Range	n	Lead Mean Range	n	Zinc Mean Range	n	Manganese Mean Range	n	Iron Mean Range	n	Nickel Mean Range	n	Cobalt Mean Range	n	Cadmium Mean Range	n
Steveston	Near South Bank	10.5 8.0-17.0	4	2.7 2.6-2.7	4	14 12-15	4	185 170-200	4	2 625 2 500-2 800	4	15 14-16	4	3.9 3.5-4.2	4	0.2 0.1-0.2	4
	Midstream	11.2 7.8-15.0	4	2.5 2.3-2.6	4	13 12-14	4	178 170-190	4	2 575 2 500-2 700	4	14 13-15	4	3.6 3.5-3.7	4	0.1 0.1	4
	Near North Bank	14.0 8.0-19.0	4	2.7 2.7	4	12 12-13	4	175 170-180	4	2 450 2 400-2 600	4	13 12-14	4	3.7 3.7	4	0.1 0.1	4
Tilbury Island	Near South Bank	12.7 12.0-13.0	3	4.2 3.9-4.7	3	19 15-23	3	210 190-230	3	5 970 4 800-7 000	3	19 16-22	3	5.8 5.0-6.3	3	0.3 0.2-0.3	3
	South of Midstream	9.0 8.8-9.2	3	2.3 2.2-2.5	3	13 12-14	3	200 190-210	3	3 600 3 300-3 900	3	14 12-16	3	3.7 3.5-3.9	3	0.1 0.1	3
	North of Midstream	8.1 7.8-8.5	3	2.2 2.1-2.3	3	12 12-13	3	203 200-210	3	3 130 3 000-3 200	3	12 12-13	3	3.4 3.4	3	0.1 0.1	3
	Near North Bank	7.3 7.0-7.5	3	3.4 3.4-3.5	2	15 14-16	3	137 120-160	3	4 130 4 000-4 200	3	11 11-12	3	3.5 3.4-3.8	3	0.1 0.1	3
Oak St. Bridge	Near South Bank	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	South of Midstream	6.5 6.0-6.9	3	3.6 3.5-3.7	3	18 17-19	3	127 120-130	3	4 200 4 000-4 300	3	14 13-14	3	4.0 3.7-4.3	3	0.1 0.1	3
	North of Midstream	5.8 5.8	3	3.2 3.1-3.4	3	16 15-17	3	100 90-110	3	3 830 3 500-4 200	3	14 11-17	3	3.5 3.3-3.6	3	0.1 0.1	3
	Near North Bank	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

[1] Inland Waters Directorate, preliminary data; means and ranges calculated by author.

* Insufficient material in this particle size range for analysis.

TABLE 3-6 (CONTINUED)

METAL CONCENTRATIONS (μg/g Dry Wt.) IN SEDIMENTS FROM THE LOWER FRASER RIVER TAKEN ACROSS THE RIVER CHANNEL. PARTICLE SIZE: >180 μm, <850 μm[1]

Site	Location in Cross-section	Copper Mean Range	n	Lead Mean Range	n	Zinc Mean Range	n	Manganese Mean Range	n	Iron Mean Range	n	Nickel Mean Range	n	Cobalt Mean Range	n	Cadmium Mean Range	n
New Westminster	Near South Bank	9.1 8.2-10.0	3	2.6 2.6-2.7	3	12 12-13	3	167 160-170	3	4 030 3 900-4 200	3	14 13-16	3	4.0 3.7-4.3	3	0.1 0.1	3
	South of Midstream	11.5 9.6-14.0	3	2.2 2.1-2.4	3	10 9-10	3	150 150	3	3 230 3 100-3 300	3	12 12-13	3	3.0 2.9-3.0	3	0.1 0.1-0.2	3
	North of Midstream	7.3 6.6-7.6	3	2.0 2.0-2.1	3	12 11-13	3	193 180-210	3	3 270 2 800-3 600	3	12 11-13	3	3.3 3.1-3.7	3	0.1 0.1-0.2	3
	Near North Bank	7.1 6.7-7.5	3	2.7 2.6-2.8	3	13 11-14	3	207 200-210	3	3 100 2 800-3 300	3	11 10-11	3	3.5 3.1-3.8	3	0.2 0.1-0.2	3

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[1] Inland Waters Directorate, preliminary data; means and ranges calculated by author.

TABLE 3-7

METAL CONCENTRATIONS (µg/g Dry Wt.) IN SEDIMENTS FROM THE LOWER FRASER RIVER TAKEN ACROSS THE RIVER CHANNEL. PARTICLE SIZE: <180 µm[1]

Site	Location in Cross-section	Copper Mean Range	n	Lead Mean Range	n	Zinc Mean Range	n	Manganese Mean Range	n	Iron Mean Range	n	Nickel Mean Range	n	Cobalt Mean Range	n	Cadmium Mean Range	n	Mercury** Mean Range	n
Steveston	Near South Bank	16 11-33	4	3.5 3.3-3.6	4	17 15-19	4	165 150-180	4	2 950 2 800-3 000	4	17 16-19	4	4.4 4.1-4.9	4	0.2 0.1-0.2	4	0.016 0.015-0.019	4
	Midstream	31 18-44	4	3.7 3.5-4.0	4	19 18-20	4	165 160-170	4	2 900 2 800-2 900	4	16 15-17	4	4.2 4.1-4.3	4	0.2 0.2-0.3	4	0.015 0.013-0.017	4
	Near North Bank	160 72-280	4	5.2 4.6-5.8	4	24 21-30	4	170 160-180	4	2 980 2 900-3 000	4	17 16-19	4	4.5 4.2-4.8	4	0.3 0.2-0.3	4	0.012 0.010-0.015	4
Tilbury Island	Near South Bank	12 11-14	3	3.7 3.4-4.1	3	15 14-16	3	170 170	3	4 700 4 300-5 100	3	15 14-15	3	4.4 4.0-4.8	3	0.3 0.2-0.3	3	0.037 0.020-0.070	3
	South of Midstream	11 -	1	6.6 4.6-9.0	3	35 15-51	3	200 180-210	3	5 400 4 600-6 400	3	21 16-25	3	5.1 4.6-5.9	3	0.2 0.1-0.3	3	0.015 0.012-0.017	3
	North of Midstream	*	*	6.7 5.6-7.6	3	36 29-44	3	200 180-210	3	6 300 5 900-6 500	3	20 18-21	3	5.4 4.7-5.9	3	0.2 <0.2-0.3	3	0.012 0.011-0.014	3
	Near North Bank	19 19	2	6.4 3.9-8.8	2	26 18-30	3	170 140-190	3	5 600 4 800-6 300	3	17 14-20	3	5.3 4.8-5.7	3	0.2 0.2	3	0.016 0.013-0.020	3
Oak St. Bridge	Near South Bank	32 30-34	3	35 32-38	3	60 58-63	3	340 300-360	3	9 200 9 100-9 300	3	21 21-22	3	9.7 9.2-10	3	0.7 0.6-0.7	3	0.082 0.075-0.085	3
	South of Midstream	*	*	6.5 5.3-7.6	3	36 31-42	3	170 150-190	3	6 300 5 000-7 800	3	21 17-26	3	6.1 5.1-7.2	3	0.2 0.1-0.3	3	0.012 0.011-0.013	3
	North of Midstream	*	*	6.2 4.6-7.4	3	42 39-47	3	140 140-150	3	5 600 5 600-5 700	3	19 17-20	3	5.3 4.4-6.0	3	<0.2 <0.1-0.3	3	0.011 0.010-0.012	3
	Near North Bank	24 23-25	3	36 32-40	3	59 58-60	3	190 170-210	3	7 300 7 000-7 600	3	16 15-16	3	7.8 6.6-7.0	3	0.4 0.4	3	0.062 0.055-0.070	3

[1] Inland Waters Directorate, preliminary data; means and ranges calculated by author.

* Insufficient material in this particle size range for analysis.

** Mercury determinations carried out on particle fraction <850 µm.

TABLE 3-7 (CONTINUED)

METAL CONCENTRATIONS (µg/g Dry Wt.) IN SEDIMENTS FROM THE LOWER FRASER RIVER TAKEN ACROSS THE RIVER CHANNEL. PARTICLE SIZE: <180 µm[1]

Site	Location in Cross-section	Copper Mean Range	n	Lead Mean Range	n	Zinc Mean Range	n	Manganese Mean Range	n	Iron Mean Range	n	Nickel Mean Range	n	Cobalt Mean Range	n	Cadmium Mean Range	n	Mercury** Mean Range	n
New Westminster	Near South Bank	12 11-12	3	3.1 3.0-3.2	3	14 14-15	3	170 160-170	3	5 100 4 900-5 200	3	15 15-16	3	4.3 4.1-4.5	3	0.2 0.2	3	0.016 0.015-0.018	3
	South of Midstream	21 19-23	3	2.8 2.5-3.0	3	14 13-15	3	180 170-190	3	5 600 5 300-6 100	3	18 17-20	3	5.2 4.8-5.4	3	0.1 0.1-0.2	3	0.015 0.013-0.018	3
	North of Midstream	*	*	6.1 3.9-8.0	3	52 35-60	3	230 200-260	3	7 300 6 500-8 600	3	16 10-19	3	5.0 5.0-5.1	3	<0.2 <0.1- 0.5	3	0.013 0.011-0.016	3
	Near North Bank	*	*	22 17-31	3	28 24-33	3	180 170-190	3	5 300 5 200-5 300	3	17 16-18	3	4.7 4.6-4.9	3	<0.2 <0.2- 0.3	3	0.009 0.007-0.011	3

[1] Inland Waters Directorate, preliminary data; means and ranges calculated by author.

* Insufficient material in this particle size range for analysis.

** Mercury determinations carried out on particle fraction <850 µm.

TABLE 3-8

PARTICLE SIZE DISTRIBUTION OF FRASER RIVER MAIN CHANNEL SEDIMENTS[1]
(THESE DATA ARE FROM THE SAME SAMPLES LISTED IN TABLE 3-9)

Sample Origin	No. of Sites In Reach	Percent of Sample Retained by Each Sieve Size					
		9.50 mm	2.36 mm	1.18 mm	0.300 mm	0.075 mm	<0.075 mm
Mainstem							
Reach 3	1	0	1.08	1.62	8.76	60.78	27.76
Reach 4	1	9.21	5.10	22.52	18.84	24.54	19.79
Main Arm							
Reach 5	1	0	0.82	0.82	1.21	94.19	2.96
M Reach 7	1	0	1.59	1.16	61.89	34.84	0.52
Reach 8	1	0	0	0.57	8.92	89.90	0.61
Reach 10	1	00	0.50	0.56	89.39	9.02	0.53
North Arm							
Reach 14	4	8.45	1.89	5.85	21.01	53.40	9.40
Reach 15	3	0.10	4.58	3.45	31.38	51.42	9.15
Reach 16	4	0.89	2.15	4.43	28.03	55.29	9.21
Reach 17	1	11.55	5.90	4.98	44.11	28.87	4.59
Reach 18	1	0	0.82	0.94	2.58	69.02	26.64

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[1] Packman, Environmental Protection Service, unpublished data.

TABLE 3-9

LEVELS OF METALS IN SEDIMENTS FROM THE FRASER RIVER MAIN CHANNEL[1]

(µg/g Dry Wt.)

Location	No. of Sites In Reach	Cadmium	Cobalt	Copper	Iron	Manganese	Nickel	Lead	Zinc	Mercury	% Organic Carbon
Fraser River Lower Mainstem											
Reach 3	1	0.285	13.6	28.4	22 270	357.5	39.1	5.5	62.8	<0.025	0.3
Reach 4	1	N.D.	15.1	35.4	23 600	378.1	47.0	9.8	75.4	<0.141	0.9
Fraser River Main Arm											
Reach 5	1	0.273	9.8	18.1	16 910	264.7	36.7	N.D.	42.2	<0.025	0.3
Reach 7	1	N.D.	9.8	19.6	16 820	261.2	37.6	1.2	41.3	<0.025	0.3
Reach 8	1	N.D.	12.2	15.9	19 550	309.3	52.4	1.1	44.0	<0.025	0.3
Reach 10	1	N.D.	11.6	17.0	20 000	285.3	45.7	5.3	49.4	<0.024	0.3
Fraser River North Arm											
Reach 14	4	0.150±0.173	11.0±2.7	22.7±8.9	18 350±3 470	275.0±57.4	36.8±8.1	23.8±21.0	90.0±45.8	<0.027±0.005	0.8
Reach 15	3	N.D.	11.7±2.7	24.5±6.0	19 620±1 940	275.0±52.0	36.7±5.7	39.0±6.9	88.5±2.1	<0.024	2.1
Reach 16	4	N.D.	10.9±0.9	24.7±4.3	19 550±370	277.6±15.7	37.8±1.8	27.9±12.5	84.4±8.5	<0.035±0.020	1.0
Reach 17	1	N.D.	10.5	22.2	19 320	213.1	39.5	29.2	78.1	<0.025	1.1
Reach 18	1	N.D.	12.5	28.4	20 450	319.7	42.6	25.7	83.5	<0.025	1.6

[1] Data courtesy of G. Packman, E.P.S., Vancouver, B.C.
Where data from more than one sample are pooled, they are reported as Means ± Standard Deviation.

N.D. Not detectable.

TABLE 3-10

LEVELS OF METALS IN MAIN ARM AND FRASER RIVER TRIBUTARY SEDIMENTS

(MEAN VALUES, µg/g Dry Wt.)

Site	Cadmium	Cobalt	Copper	Iron	Lead	Manganese	Nickel	Zinc	Mercury
Fraser R., Main Arm									
U/S Lulu STP Outfall,[1] North of Kirkland Is.; n=2	0.65	21.0	18.5	12 860	4.5	328	35	32	-
D/S Lulu STP Outfall,[1] South of Steveston Is.; n=2	0.65	26.0	19.0	13 280	4.0	312	38	28	-
Upstream End of[1] Canoe Pass; n=1	0.70	16.0	18.0	13 390	4.0	308	43	33	-
Sand Heads and Down-[1] stream; n=2	0.70	22.0	26.0	16 740	8.0	322	50	47	-
Brunette Basin; n=36[2]	0.28	13.0	124.0	29 000	199.0	426	19	138	0.03
n=13[3]	-	-	56.3	24 000	204.0	520	-	104	-
Salmon Basin; n=9[3]	-	-	16.8	22 440	39.3	610	-	62	-

[1] B.C. Research, 1973.

[2] Hall *et al.*, 1976.

[3] Bindra and Hall, 1977.

U/S Upstream.

D/S Downstream.

n Number of samples.

- No data.

TABLE 3-11

PARTICLE SIZE ANALYSIS OF BACKWATER SEDIMENTS FROM THE FRASER RIVER

Site	No. of Samples	Percent Particles in Each Size Class Based on Mean Values			% Organic Carbon
		Medium and Coarse Sand (2.0-0.25 mm)	Fine Sand (0.25-0.0625 mm)	Silt and Clay (<0.0625 mm)	
At Barnston[1] Island	2	11.5	38.0	50.5	0.8 (n=6)
Downstream[1] Poplar Island	2	15.5	27.5	57.0	0.6 (n=5)
At Mitchell[1] Island	2	5.0	23.0	72.0	0.9 (n=4)
Downstream[1] Annacis Island	2	1.5	8.5	90.0	1.0 (n=5)
Ladner Reach[1]	1	1.0	29.0	70.0	0.6 (n=1)
Ladner Side[2] Channel	20	0.0	20.0	80.0	7.5 (n=4)
Willamson[2] Slough	4	Range <1.0-83	Range 16-92	Range <1.0-25	

[1] W.I.B., unpublished data.
[2] Hall, 1979.
n No. of samples.
- No data.

TABLE 3-12

METAL CONCENTRATIONS IN BACKWATER SEDIMENTS OF THE FRASER RIVER

(µg/g Dry Wt.)

Site	Arsenic Mean Range	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
At Barnston[1] Island; n=5	- -	1.4 <1.0-3.0	- -	26.4 24.0-28.0	22 700 21 000-24 800	12.2 6.0-20.0	451 418-527	41.8 35.0-50.0	54.6 48.0-62.0	0.07 0.05-0.11
At New Westminster[2]; n=38	- -	< 2.2 <1.0-19.0	11 3.9-22	30.6 21.0-42.0	12 300 8 800-17 000	142 18.0-370	328 230-440	30.9 23.0-39.0	211 55.0-470	0.10 0.05-0.36 (n=32)
Downstream[1] Poplar Island; n=4	- -	<1.2 <1.0-2.0	- -	29.0 26.0-34.0	25 000 22 000-29 800	26.0 12.0-40.0	450 369-510	39.5 36.0-43.0	115 74.0-130	0.08 0.06-0.11
At Mitchell[1] Island; n=3	- -	1.7 1.0-3.0	- -	29.0 25.0-33.0	23 000 20 300-26 100	39.0 32.0-45.0	378 317-479	40.0 31.0-50.0	117 100-136	0.09 0.06-0.12
At Oak St.[2] Bridge; n=35	- -	<1.6 <1.0-< 2.0	12 7.5-16	32.8 27.0-43.0	13 700 9 300-19 000	44.1 27.0-76.0	315 230-430	32.8 26.0-46.0	114 80.0-170	0.06 0.04-0.09
Downstream[1] Annacis Island; n=4	- -	<1.5 < 1.0-3.0	- -	28.8 23.0-32.0	27 400 26 500-30 600	11.5 9.0-20.0	562 525-583	45.0 39.0-60.0	68.8 58.0-95.0	0.08 0.06-0.10
Ladner Reach[1]; n=1	4.0 -	4.0 -	- -	31.0 -	25 100 -	10.0 -	427 -	40.0 -	- -	0.08 -
Ladner Side-[3] Channel; n=21	- -	< 0.3 N.D.-0.6	- -	63.0 41.0-118	40 400 35 000-47 700	25.7 16.0-51.0	621 527-717	79.3 63.0-170	115 83.0-200	- -
Ladner Side-[4] Channel; n=?	- -	- -	- -	51.3 -	- -	18.9 -	- -	- -	105 -	- -
Williamson[3] Slough; n=4	- -	0.2 0.1-0.3	- -	28.5 18.0-41.0	31 200 18 700-41 000	12.5 11.0-17.0	471 355-580	90.5 51.0-168	57 41.0-79.0	- -

[1] W.L.B., unpublished data.
[2] Chapman et al., in preparation; means and ranges calculated by author.
[3] Hall, 1979.
[4] Bourque and Adams, 1975.
- No Data.
N.D. Not Detectable.
n Number of samples.

TABLE 3-13

METAL LEVELS (MEANS) IN SEDIMENTS OF OTHER DRAINAGES

(μg/g Dry Wt.)

Location	Cadmium	Cobalt	Copper	Iron	Lead	Manganese	Nickel	Zinc	Mercury	Reference
Columbia River, B.C., U/S From the Smelter at Trail	<0.5	-	29.0	15 500	19.0	333	-	44.3	0.38	Kootenay Air and Water Quality Study, Phase II. Water Quality in the Lower Columbia River, 1979.
Columbia River, B.C., 0.8 km D/S and on the Same Side as the Smelter at Trail	5.3	-	1 930	189 000	866.0	2 960	-	12 600	2.52	
Skeleton Creek, Oklahoma, Means for Five Sites	-	-	1.8	-	3.5	-	-	9.2	-	Namminga and Wilhm, 1977.
Illinois River, Illinois, Means for Five Sites	2.0	6.0	19.0	-	28.0	-	270	81.0	-	Mathis and Cummings, 1973.
Willamette River, Oregon Upstream Reach (<180 μm)	0.9	-	34.0	-	30.0	-	-	140	0.23	Rickert et al., 1977
Willamette River, Newbert Pool (<180 μm)	0.7	-	35.0	-	24.0	-	-	204	0.18	"
Willamette River, Tidal Reach (<180 μm)	1.2	-	45.0	-	43.0	-	-	419	0.14	"

U/S - Upstream
D/S - Downstream
- - No data

TABLE 3-14

LEVELS OF METALS IN SEDIMENTS FROM STURGEON AND ROBERTS BANKS UPPER 26 cm OF CORES (μg/g Dry Wt.) (FLETCHER, 1976)

	Station No. (Refer to Figure 16)	Cobalt	Copper	Iron	Manganese	Nickel	Lead	Zinc
Sturgeon Banks, Upper Tidal Flats, Not Under the Influence of the Iona Is. STP Effluent	60	13.07	19.20	19 700	245.32	37.69	8.89	56.12
	11	11.02	23.47	25 900	247.64	42.34	8.94	62.83
	35	11.96	27.34	24 200	278.44	42.48	10.98	64.51
	36	14.03	27.06	26 000	270.26	46.65	5.74	65.36
	33	12.25	31.29	25 400	256.32	46.34	8.33	68.99
Mean Values For Sturgeon Banks		12.47	25.67	24 240	260.00	43.10	8.60	63.60
Roberts Bank, North of Western Terminal, Upper Tidal Flats	31	11.84	32.94	25 200	325.26	50.28	4.06	64.87
	19	9.56	18.89	20 600	261.67	38.40	N.D.	42.60
	34	14.52	34.55	26 600	247.96	46.16	7.40	69.44
	37	13.20	35.26	26 000	338.77	44.60	3.50	64.10
	16	11.73	13.34	21 800	281.23	51.44	N.D.	44.50
	18	9.25	14.77	19 500	247.72	40.21	N.D.	36.73
	38	11.32	25.90	25 600	322.11	44.90	3.42	56.09
	12	10.84	22.52	22 600	288.64	43.86	4.91	54.72
Mean Values For Roberts Bank		11.53	24.77	23 490	289.00	45.00	2.90	54.13

N.D. Not detectable.

TABLE 3-15

LEVELS OF METALS IN SEDIMENTS FROM THE TIDAL FLATS AND THE VICINITY OF THE IONA ISLAND JETTY

(µg/g Dry Wt.)

Origin of Samples and Year of Sampling	No. Of Samples	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
North of Iona Jetty										
1973[1]	8	0.6 0.4-0.9	15 11-17	15.4 13.0-18.0	17 760 16 000-19 200	5.6 4.0-8.0	273 232-335	34 31-37	54.0 50.0-58.0	-
1974[2]	5	<0.6 <0.6	9.0 8.0-10	11.9 10.0-13.0	17 200 15 400-18 800	5.0 2.0-8.0	270 236-304	31 27-35	39.6 38.0-41.0	-
1976[3]	5	<0.4 <0.4	10 10	13.4 10.0-18.0	17 920 17 000-19 400	5.8 4.0-7.0	256 230-316	27 26-28	41.8 38.0-46.0	0.04 0.01-0.07
Close to Iona Outfall										
1973	2	3.7 1.6-5.8	22 14-30	100 33.0-168	25 850 19 300-37 400	108 27.0-189	320 293-347	52 38-65	172 81.0-262	-
1974	4	2.6 1.4-3.8	11 10-14	206 47.0-331	29 650 20 000-37 400	142 40.0-216	315 252-379	48 42-52	219 82.0-303	-
1976	2	3.7 2.5-4.9	14 13-14	209 188-230	28 300 25 600-31 000	186 136-236	289 280-298	42 37-47	246 202-290	1.22 0.95-1.50
West of the Outfall (Effluent Channel) and South of the Jetty										
1973	32	1.1 0.5-3.9	22 13-45	40.3 15.0-117	22 770 15 000-30 700	27.2 9.0-109	279 151-514	45 32-63	88.2 47.0-195	-
1974	37	0.9 0.6-3.0	11 8.0-18	43.4 12.0-198	23 590 16 400-34 500	26.9 5.0-173	302 180-694	41 27-53	79.7 40.0-224	-
1976	22	0.6 0.4-1.9	12 10-15	46.5 11.0-176	22 460 16 400-32 800	29.4 7.0-120	297 190-600	34 27-44	81.5 43.0-206	0.18 0.04-0.67

[1] B.C. Research, 1973.
[2] B.C. Research, 1975.
[3] B.C. Research, 1977.
- No data.

TABLE 3-15 (CONTINUED)

LEVELS OF METALS IN SEDIMENTS FROM THE TIDAL FLATS AND THE VICINITY OF THE IONA ISLAND JETTY

(μg/g Dry Wt.)

Origin of Samples and Year of Sampling	No. Of Samples	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
West, in the Effluent[4] Channel	8	-	-	123 21.0-302	40 490 31 300-46 500	110 41.0-219	472 418-500	-	155 67.0-301	-
South of the Iona[5] Jetty	28	-	11 8.0-16	16.9 11.0-44.0	19 000 15 900-28 500	3.8 N.D.-29.0	208 142-346	40 33-52	47.8 35.0-89.0	-
Tidal Flats-Roberts and[6] Sturgeon Banks Combined	263	-	13 8.0-15	17.9 10.0-43.0	19 500 14 700 25 300	5.5 N.D.-63.0	348 193-522	46 35-77	54.6 38.0-95.0	-

[4] Bindra and Hall, 1977.

[5] Fletcher, 1976.

[6] Grieve and Fletcher, 1976.

N.D. Not Detectable.

- No Data.

TABLE 3-16

METAL CONCENTRATIONS IN ALGAE WITH SEDIMENTS AND IN SEDIMENT FREE SAMPLES FROM THE FRASER RIVER AT MARPOLE, JUNE 21, 1979 (μg/g Dry Weight) (Ennis, personal communication)[1]

Metal	Algae With Associated Sediment (n=3) Range	Sediment Free Algae (n=3) Range
Copper	44-48	25-34
Iron	27 000-29 000	2 100-4 200
Lead	24-27	9.4- 25*
Manganese	1 100-1 300	240-380
Zinc	94-100	37-58
Cadmium	< 1- 1*	< 1- 1*
Cobalt	24-25	B.D.L.
Nickel	52-57	20

1 - Inland Waters Directorate, unpublished data.

* - Near detection limit - approximate value.

B.D.L. - Below detection limit, these B.D.L. values do not necessarily indicate low values because the D.L. is related to the biomass of tissue analysed. For example a "light" sample would have a much higher detection limit than a "heavy" sample.

n - Number of samples.

TABLE 3-17

LEVELS OF TRACE METALS IN ALGAE FROM THE FRASER RIVER AND STURGEON BANK (µg/g Dry Wt.)

Location and Algae Sampled	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
Fraser R. at New Westminster, Mixed Periphyton[1]	1.7 0.6-8.5	21.1 10.0-30.0	45.7 22.5-78.0	- -	50.7 13.0-140	1 050 375-1 900	50 16-65	153 80.0-440	0.14 0.04-0.64
Fraser R. at Marpole,[1] Mixed Periphyton	1.7 0.6-7.0	22.2 9.0-56.0	50.0 26.0-208	- -	54.5 18.0-200	1 090 250-2 100	54 30-80	185 30.0-990	0.09 0.04-0.23
Fraser R. at Steveston,[1] Mixed Periphyton	1.2 0.6-3.4	16.7 6.0-25.0	46.3 21.0-109	- -	23.8 17.0-44.0	1 060 610-2 600	46 18-72	94.4 60.0-120	0.08 0.04-0.12
Fraser R., North Side[2] Iona Island Jetty, Fucus gardneri	2.0 1.6-2.2	3.2 2.0-4.0	9.7 7.0-11.0	230 127-329	<4.0 -	142 113-159	3.8 3.2-4.2	38.8 32.0-46.0	- -
Fraser R., South Side[2] Iona Island Jetty in Sewage Channel Fucus gardneri	4.3 3.0-6.7	4.0 3.0-5.0	18.0 11.0-35.0	589 145-1 614	<9.8 <4.0-27.0	164 148-179	3.8 3.1-4.8	122 50.0-230	- -

[1] Ennis, Inland Waters Directorate, unpublished data.
[2] B.C. Research, 1975.
- No data.

TABLE 3-18

LEVELS OF TRACE METALS IN ALGAE FROM VARIOUS LOCATIONS

(µg/g Dry Wt.)

Location and Algae Sampled	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
Still Creek, Brunette[1] Basin, B.C., Mixed Periphytic Algae	-	-	349 117-529	42 300 7 320-79 000	881 226-1 440	10 800 415-49 200	-	1 300 199-4 740	-
Swansea Valley,[2] Wales, Adjacent to Smelting Waste; Mixed Periphytic Algae	- -	- -	660 380-1 330	29 300 9 970-49 500	5 750 2 600-14 200	- -	290 150-700	26 570 17 400-45 900	- -
Swansea Valley,[2] Wales, Near Smelting Waste; Mixed Periphytic Algae	- -	- -	610 340-1 020	17 600 2 800-42 300	1 700 580-2 380	- -	490 110-1 070	4 890 1 880-9 260	- -
Swansea Valley,[2] Wales, Distant From Smelting Waste; Mixed Periphytic Algae	- -	- -	140 50.0-290	3 950 460-8 930	150 40.0-230	- -	80.0 30.0-130	980 120-1 920	- -
Strother Cr., 0-1 Mile[3] D/S Tailings Dam, Missouri; Potamogeton	- -	- -	- -	- -	- 1 300-11 500	- -	- -	- 500-6 700	- -

[1] Bindra and Hall, 1977.
[2] Trollope and Evans, 1976.
[3] Hardie *et al.*, 1974.
- No data.

TABLE 3-18 (CONTINUED)

LEVELS OF TRACE METALS IN ALGAE FROM VARIOUS LOCATIONS

(µg/g Dry Wt.)

Location and Algae Sampled	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
Snow Water, Kulusuk,[4] Greenland; *Chlamydomonas nivalis*	1.0 -	25.0 -	10.0 -	7 500 -	- -	40.0 -	10.0 -	20.0 -	- -
Menai Straits, Wales,[5] No Large Source of Contamination; *Fucus vesiculosus*	2.1 -	- -	9.0 7.4-10.0	218 146-360	3.2 -	103 89.0-130	8.1 7.1-8.9	116 98.0-138	- -
Solent Region, England[6] Receives Three Rivers; *Laminari digitata*	0.2 -	- -	- -	- -	- -	- -	- -	- -	0.17 -
Severn Estuary, Great[6] Britain; *Fucus serratus*	53 -	- -	- -	- -	- -	- -	- -	600 -	0.08 -

[4] Fjeringstad, 1973.
[5] Foster, 1976.
[6] Leatherland and Burton, 1974.
- No data.

TABLE 3-19

METAL LEVELS IN AMPHIPODS FROM THE LOWER FRASER

(µg/g Dry Wt.)

Site	Species	No. of Samples	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Nickel	Zinc	Mercury
Oak Street[1]	Anisogammarus confervicolus	1	< 3.0	-	8.3	50.0	1 200	18.0	40.0	18.0	76.0	0.06
Westham Island[1]	A. confervicolus*	3	< 3.0	-	6.4	85.0	1 270	18.5	87.0	6.9	75.0	0.05
	Corophium	1	< 8.0	-	< 16.0	55.0	3 000	< 40.0	94.0	< 16.0	< 55.0	-
Ladner Reach[2]	A. confervicolus	1	3.0	26.0	-	104	7 270	45.0	937	554	181	1.15

[1] Chapman et al., in preparation; conversions from µg/g tissue dry weight to µg/g sample dry weight and mean calculations by author.
[2] W.I.B., unpublished data.
* Mean Values.
- No data.

TABLE 3-20

SUMMARY OF AGENCIES WHICH HAVE ANALYSED HEAVY METALS IN FRASER RIVER BIOTA* AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(1) Chapman et al., 1980 and in preparation	Inland Waters Directorate	Water Quality Branch, Analytical Services Lab	1) Sort Organisms Live 2) Rinse Twice in Glass Distilled Water 3) Freeze Dry Tissue (Air Dry for Hg) 4) Pulverize 5) Required a Biomass Minimum of 0.1 g Dry Weight (0.125 g Dry Wt. for Hg)	1) Digest with H_2O_2 2) Heat for 2 Hours 3) Digest with HNO_3 4) Heat for 0.5 Hours 5) Analyse Filtrate with AAS	1) Digest with $HNO_3 + H_2SO_4 + HCl$ 2) Boil 3) Add $K_2S_2O_8$ 4) Filter and Analyse Filtrate with FAAS
(2) W.I.B., unpublished data; Appendix I	Water Investigations Branch	Environmental Lab (B.C.)	1) Sort Organisms Live 2) Rinse Twice in Glass Distilled Water 3) Freeze Organisms 4) Dry Tissue at 105°C 5) Pulverize 6) Minimum Biomass Requirement 0.5-1.0 g Dry Weight	1) Digest with $HNO_3^- HClO_4$ 2) Boil for 2 Hours 3) Analyse Filtrate with PES	1) Digest with $H_2SO_4 + HNO_3$ 2) Heat to 60°C for 0.5 Hours 3) Cool and Add $KMnO_4$ 4) Add $K_2S_2O_8 + KMnO_4$ 5) Let Stand Overnight 6) Add Hydroxylamine-Sodium Chloride 7) Add Stannous Chloride 8) Analysis with FAAS

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* Zoological (animal) tissues only.

TABLE 3-20 (CONTINUED)

SUMMARY OF AGENCIES WHICH HAVE ANALYSED HEAVY METALS IN FRASER RIVER BIOTA AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
		Laboratory Services, Pacific Region (EPS-FMS)	1) Sort Organisms Live 2) Rinse Twice in Glass Distilled Water 3) Freeze Organisms 4) Freeze Dry 5) Pulverize 6) Requires a Biomass of 0.5 g Dry Weight (0.15 g Dry Wt. for Hg)		1) Digest with H_2SO_4 2) Let Stand Overnight 3) Add H_2O_2 and Heat 4) Cool, Add $KMnO_4$ 5) Analyse with FAAS
(3) Bindra and Hall, 1977	Westwater Research Centre	U.B.C., Environmental Engineering Laboratory	1) Sieve Field Collection Through a 0.38 mm Mesh Sieve 2) Preserve Sievate in Formaldehyde 3) Dry Sorted Organisms at 70°C Overnight 4) Pulverize	1) Digest Organisms with H_2O_2 Over Medium Heat 2) Digest with HNO_3 3) Analyse for Metals with AAS 4) Correct Data for Sediment in Organisms' Guts	
(4) Hall, 1979	Westwater Research	Can Test	1) Sieve Field Collections 2) Preserve Sievate in Formaldehyde 3) Dry Sorted Organisms at 110°C	1) Digest with HNO_3-HC1-H_2O_2 2) Analyse with AAS or Graphite Furnace	

TABLE 3-20 (CONTINUED)

SUMMARY OF AGENCIES WHICH HAVE ANALYSED HEAVY METALS IN FRASER RIVER BIOTA AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(5) Bawden *et al.*, 1973	Westwater Research Centre	U.B.C., Dept. of Oceanography	1) Homogenize Fresh Tissue 2) Freeze 3) Freeze Dry 4) Grind Tissue, Pass Through Sieve of 177 µ m Mesh	1) Digest with HNO_3-HCl 2) Analyse with AAS	1) Digest with H_2SO_4-H_2O_2 2) Add $KMnO_4$ 3) Add Stannous Chloride 4) Analyse with FAAS
(6) B.C. Research, 1975	B.C. Research	B.C. Research	1) Dry Fresh Tissues or Specimens at 105°C	1) Digest with HNO_3 for 12-24 Hours 2) Analyse Filtrate with AAS	
(7) McGreer, 1979 a	U.B.C.	B.C. Research	1) Allow Specimens to Depurate of Sediments for 24 Hours 2) Dry Tissue at 105°C (Air Dry for Hg)	1) Digest with HNO_3-$HClO_4$ 2) Analyse Filtrate with AAS	1) Digest with HCl-HNO_3 at 95°C 2) Add $KMnO_4$ and Potassium Persulphate at 95°C for 0.5 Hours 3) Add Hydroxlyamine-HCl 4) Reduce with Stannous Chloride 5) Analyse with FAAS

TABLE 3-20 (CONTINUED)

SUMMARY OF AGENCIES WHICH HAVE ANALYSED HEAVY METALS IN FRASER RIVER BIOTA AND THE PROCEDURES USED

Reference Cited	Agency	Laboratory	Pretreatment	Extraction Technique For A Range of Metals	Extraction Technique For Mercury
(8) DeMill, unpublished data	Environmental Protection Service	Laboratory Services, Pacific Region (EPS-FMS)	1) Freeze Soft Tissues or Process Fresh 2) Freeze Dry Tissues 3) Blend 4) Requires a Biomass of 0.5 g Dry Weight (0.15 g Dry Weight for Hg)	1) Digest with HNO_3 2) Heat for 1 Hour 3) Add HNO_3 4) Analyse with AAS	Refer to (2) above Laboratory Services, Pacific Region
(9) Northcote, Johnston and Tsumura, 1975	Westwater Research Centre	U.B.C., Geological Sciences Centre	1) Freeze Tissue 2) Dry at 100°C	1) Digest with HNO_3 and HCl 2) Analyse with AAS	1) Digest with H_2SO_4-H_2O_2 2) Reduce with Stannous Chloride 3) Analyse with FAAS
(10) Drinnan and Northcote, in preparation		Environmental Lab (B.C.)	Refer to (2) above Environmental Lab (B.C.)	Refer to (2) above	Refer to (2) above, Environmental Lab (B.C.)
(11) McGreer and Vigers, 1979	EVS Consultants	Laboratory Service Pacific Region (EPS-FMS)	Refer to (8) above	Refer to (8) above	Refer to (2) above, Laboratory Services, Pacific Region

TABLE 3-21

TRACE METALS IN BENTHIC INVERTEBRATES FROM THE FRASER RIVER*

(µg/g Dry Wt.; W.I.B., unpublished data)

Site	Sampling Time	Arsenic	Cadmium	Copper	Chromium	Iron	Lead	Manganese	Nickel	Zinc	Mercury
North of Western Tip of Barnston Island	W/S	4.0	1.0	34.0	7.0	6 680	10.0	291.0	13.0	130.0	0.446
	S/F	25.0	<1.0	21.0	-	3 030	4.0	108.0	10.0	127.0	0.537
Downstream Poplar Island	W/S	-	-	-	-	-	-	-	-	-	0.500
	S/F	16.0	<1.0	15.0	-	3 010	10.0	74.0	7.0	152.0	1.780
South of Western Tip of Mitchell Island	W/S	-	-	-	-	-	-	-	-	-	1.250
	W/S	-	<1.0	22.0	8.0	5 610	12.0	85.0	10.0	150.0	0.588
	S/F	17.0	<1.0	11.0	-	2 680	8.0	52.0	5.0	82.0	0.586
Downstream Annacis Island	W/S	3.0	<1.0	26.0	5.0	4 240	9.0	80.0	7.0	129.0	0.990
	S/F	32.0	<1.0	21.0	-	2 870	3.0	81.0	7.0	160.0	0.643

* - For sample composition refer to Appendix I, Table I-B.
W/S - Winter/Spring.
S/F - Summer/Fall.
- - No data.

TABLE 3-22

CONCENTRATIONS OF METALS IN OLIGOCHAETES FROM THE FRASER RIVER

(μg/g Dry Wt.)

Site	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
New Westminster[1] n=13	<2.3 <1.0-5.1*	3.4 <2.0-4.9 (0.31)	20.4 11.8-35.3 (0.67)	3 280 1 030-5 400 (0.27)	39.0 4.1-72.0 (0.27)	90.5 37.4-152 (0.28)	5.3 3.0-13 (0.17)	122 82.4-153 (0.58)	0.43(n=9) 0.12-1.80 (4.30)
Oak Street[1] n=12	<2.2 <1.0-5.1*	4.1 <2.0-<9.0 (0.34)	14.6 8.9-25.2 (0.44)	2 500 905-4 500 (0.18)	11.6 5.5-21.6 (0.26)	58.1 23.5-146 (0.18)	6.2 2.5-12 (0.19)	82.9 47.1-125 (0.73)	0.10 0.09-0.14 (1.67)
Ladner Side[2] Channel n=4	<0.3 <0.2-<0.5 (0.86)	-	27.0 19.0-40.0 (0.43)	-	5.4 3.2-7.1 (0.21)	-	-	67.0 40.0-96.0 (0.58)	-

[1] Chapman et al., 1980 and in preparation; conversions from μg/g tissue dry weight to μg/g sample dry weight and data calculations by author.

[2] Hall, 1979.

( ) Bioconcentration Factor = $\frac{\text{Concentration of metal in organism}}{\text{Concentration of metal in sediment (Table 3-12)}}$

* Bioconcentration Factors not calculated due to proximity of some values to detection limits in biota or sediments.

n Number of samples.

- No data.

TABLE 3-23

DOMINANT OLIGOCHAETE SPECIES FROM FRASER RIVER SITES

Site	Dominant Species
North of Western Tip of[1] Barnston Island	*Limnodrilus hoffmeisteri*; *Ilyodrilus frantzi*; *I. frantzi capillatus*
New Westminster[2]	*Limnodrilus hoffmeisteri*; *Tubifex tubifex*
Downstream Poplar Island[2]	*Limnodrilus hoffmeisteri*; *Tubifex tubifex*; *Ilyodrilus mastix* (n. sp)
South of Western Tip of[2] Mitchel Island	*Limnodrilus hoffmeisteri*; *Iloydrilus frantzi*; *Tubifex tubifex*
Oak Street[1]	*Limnodrilus hoffmeisteri*; *Tubifex tubifex*
Downstream Annacis Island[2]	*Limnodrilus hoffmeisteri*; *Tubifex tubifex* *Ilyodrilus frantzi capillatus*

[1] W.L.B., unpublished data.
[2] Chapman *et al.*, 1980.

TABLE 3-24

CONCENTRATIONS OF METALS IN CHIRONOMID LARVAE FROM THE FRASER RIVER

(µg/g Dry Wt.)

Site	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury Mean Range
New Westminster[1] n=2	<19 <2.0-<36*	<46 <3.0-<90*	36.4 26.5-46.4 (1.19)	2 040 1 330-2 750 (0.17)	51.2 12.5-<90.0 (0.36)	72.1 66.2-75.0 (0.22)	<46.5 <3.0-<90.0	138 70.2-206 (0.65)	-
Oak Street[1] n=3	<66 <8.0-166*	<38 <17-<66*	32.4 27.5-41.9 (0.99)	5 000 1 840-7 780 (0.36)	32.0 <10.0-52.1 (0.73)	91.3 73.8-103 (0.29)	<39.3 <17.0-<66.0*	149 120-205 (1.3)	0.09 - (1.5)
Ladner Side[2] Channel n=1	1.2 (4.00)	-	19.0 (0.57)	-	5.1 (0.18)	-	-	152 (1.36)	-

1 Chapman et al., in preparation; conversions from µg/g tissue dry weight to µg/g sample dry weight and data calculations by author.

2 Hall, 1979.

( ) Bioconcentration Factor = $\frac{\text{Concentration of metal in organism}}{\text{Concentration of metal in sediment (Table 3-12)}}$

* Bioconcentration Factor not calculated due to proximity of some values to detection limits in biota or sediments.

n Number of samples.

- No data.

TABLE 3-25

MEAN CONCENTRATIONS OF METALS IN BENTHIC INVERTEBRATES FROM THE FRASER RIVER* (W.I.B., unpublished data)

(μg/g Dry Wt.)

Site	Cadmium	Copper	Iron	Lead	Manganese	Nickel	Zinc	Mercury
North of the Western Tip of Barnston Island	1.0 (0.71)	27.5 (1.04)	4 855 (0.21)	7.0 (0.57)	119.5 (0.44)	11.5 (0.28)	128.5 (2.35)	0.49 (6.65)
Downstream From Poplar Island	1.0 (0.80)	15.0 (.72)	3 010 (0.12)	10.0 (0.38)	74.0 (0.16)	7.0 (0.18)	152.0 (1.32)	0.26 (3.23)
South of Western Tip of Mitchell Island	1.0 (0.60)	16.5 (0.57)	4 145 (0.18)	10.0 (0.26)	68.5 (0.18)	7.5 (0.19)	116.0 (0.99)	0.81 (8.69)
Downstream of Annacis Island	1.0 (0.67)	23.5 (0.82)	3 555 (0.13)	6.0 (0.52)	80.5 (0.14)	7.0 (0.16)	144.5 (2.10)	0.82 (10.2)

* - Refer to Appendix I, Table I-B for sample composition.

( ) - Bioconcentration Factor $= \frac{\text{Concentration of metal in organism (Table 3-25)}}{\text{Concentration of metal in sediment (Table 3-12)}}$

TABLE 3-26

METAL LEVELS IN BENTHIC INVERTEBRATES OF VARIOUS SYSTEMS

(µg/g Dry Wt.)

Location	Organisms	Cadmium Mean Range	Chromium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range
Brunette Basin[1]	Oligochaetes	- -	- -	- -	119 10.1-733	13 450 10 500-14 600	486 147-1 230	863 222-3 130	- -	438 204-667
Salmon Basin[1]	Oligochaetes	- -	- -	- -	32.9 13.2-58.0	8 900 4 960-11 600	18.9 0.88-39.1	800 476-1 140	- -	289 124-549
	Chironomid Larvae	- -	- -	- -	22.0 14.7-27.2	1 410 54-4 500	7.9 2.70-13.2	50.9 21.0-93.2	- -	170 154-192
Skeleton Creek,[2] Oklahoma	Chironomid Larvae	- -	3.0 -	- -	1.9 -	- -	1.3 -	- -	- -	57.1 -
Illinois R.,[3] Illinois	Oligochaetes	1.1 0.5-3.2	10 4.0-21	1.6 0.2-2.5	23.0 10.0-42.0	- -	17.0 6.0-39.0	- -	11 4.0-18	41.0 13.0-62.0
Columbia R.,[4] U/S Smelter at Trail, B.C.	Immature Insects	2.5 -	- -	- -	- -	- -	19.7 -	- -	- -	198 -
Columbia R.,[4] 10 km D/S Smelter at Trail, B.C.	Immature Insects	7.6 -	- -	- -	- -	- -	383 -	- -	- -	952 -

[1] Bindra and Hall, 1977.

[2] Namminga and Wilhm, 1977.

[3] Mathis and Cummings, 1973.

[4] Kootenay Air and Water Quality Study Phase II, 1979.

- No data.

U/S Upstream.

D/S Downstream.

TABLE 3-27

METAL LEVELS IN BIVALVES FROM STURGEON AND ROBERTS BANKS (µg/g Dry Wt.)

Species and Collection Location	Cadmium Mean Range	Chromium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Silver Mean Range	Zinc Mean Range	Mercury Mean Range
Crossostrea gigas[1] North Side Iona Island Jetty	19.3 17.9-20.1	<6 <6	<2 <2	410 355-470	793 448-1 136	<4.0 <4.0	40.8 35.7-43.6	<2 <2	7.3 5.4-9.1	3 166 2 909-3 622	- -
Crossostrea gigas[1] South Side Iona Island Jetty	17.7 10.0-26.7	<6.9 <6-9.5	<2 <2	477 280-557	1 617 998-3 481	6.3 <4.0-12.3	36.4 24.3-44.0	<2 <2	8.1 4.3-11.9	3 294 2 836-3 838	- -
Crossostrea gigas[2] West End, North Side Iona Island Jetty	12.0	-	<8	400	-	<2.0	48.0	<7	28.0	2 400	0.220
Cardium corbis[2] Roberts Bank	<1.0	-	<6	9.4	-	<2.0	13.0	9	<1.4	120	0.080
Mya arenaria[2] Sturgeon Bank, North of Iona Jetty	<1.0	-	<8	30.0	-	2.0	25.0	8	17.0	72.0	0.370

[1] B.C. Research, 1975.
[2] Bawden *et al.*, 1973.
- No data.

TABLE 3-28

CONCENTRATIONS OF METALS IN BIVALVES FROM VARIOUS LOCATIONS

(μg/g Dry Wt.)

Species and Sample Location	Cadmium Mean Range	Chromium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Silver Mean Range	Zinc Mean Range	Mercury* Mean Range
Crossostrea gigas											
Alberni Inlet,[1] B.C.	< 3.3 <2.5-6.0	- -	- -	61.3 39.0-110	- -	- -	- -	- -	- -	10 650 7 500-16 000	0.182 -
Nanoose Harbour[1] Lasqueti Island, B.C.	15.6 5.1-28	- -	- -	236 72.0-420	- -	- -	- -	- -	- -	1 300 1 100-1 800	- -
Discovery Passage,[1] B.C.	10.1 5.6-17	- -	- -	162 89.0-310	- -	- -	- -	- -	- -	5 043 2 200-9 500	0.036 0.036-0.037
Sooke Basin, B.C.[1]	<3.4 <3.0- <4.0	- -	- -	51.2 41.0-65.0	- -	- -	- -	- -	- -	1 300 1 100-1 800	- -
Howe Sound, B.C.[2] (1974)	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.120 0.05-0.16
Oregon, Mean Value[3] for 10 stations	- -	- -	- -	94.0 -	422 -	- -	34.7 -	- -	- -	2 580 -	- -
Seaward of[4] Lauceston, Tasmania, Australia	30.5 -	- -	- -	564 -	- -	- -	- -	- -	- -	4 826 -	- -
Cardium corbis											
Cowichan Bay,[5] B.C.	<1.3 -	- -	<8.0 -	13.0 -	- -	< 2.0 -	25.0 -	<7.0 -	< 1.3 -	130.0 -	0.104 -

[1] Nelson and Goyette, 1976.
[2] Harbo and Birtwell, 1978.
[3] Windom and Smith, 1972.
[4] Ratowsky et al., 1974.
[5] Bawden et al., 1973.
* Mercury data are μg/g wet weight.
- No data.

TABLE 3-28 (CONTINUED)

CONCENTRATIONS OF METALS IN BIVALVES FROM VARIOUS LOCATIONS

(μg/g Dry Wt.)

Species and Sample Location	Cadmium Mean Range	Chromium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Silver Mean Range	Zinc Mean Range	Mercury* Mean Range
Mya arenaria											
Cowichan Bay, B.C.[5]	<1.3 -	- -	<8.0 -	13.0 -	- -	<2.0 -	93.0 -	<7.0 -	<1.3 -	69.0 -	0.170 -
Alberni Inlet, B.C.[1]	- -	- -	- -	16.8 8.0-31	- -	- -	- -	- -	- -	266.0 150.0-430.0	- -
Tapes semidecussata											
San Fransisco Bay,[6] California	9.6 -	10.3 -	- -	19.2 -	- -	<2.2 -	24.7 -	- -	7.3 -	11.2 -	- -
Protothaca staminea											
Elkhorn Slough,[6] Monterey Bay, California	5.7 -	<1.5 -	- -	7.5 -	- -	5.2 -	11.5 -	- -	<1.0 -	67.7 -	- -
Alberni Inlet, B.C.[1]	- -	- -	- -	9.8 5.0-17.0	- -	- -	- -	- -	- -	207.4 87.0-390.0	-
Campbell River,[1] Area, B.C.	- -	- -	- -	14.8 10.0-40.0	- -	- -	- -	- -	- -	118.1 50.0-170.0	- -
Saxidomus giganteus											
Discovery Passage,[1] B.C.	- -	- -	- -	37.3 14.0-110	- -	- -	- -	- -	- -	118.3 90.0-130.0	- -

[1] Nelson and Goyette, 1976.
[5] Bawden et al., 1973.
[6] Graham, 1972.
* Mercury data are μg/g wet weight.
- No data.

TABLE 3-29

METAL CONCENTRATIONS IN SOFT TISSUES OF CLAMS (Macoma, Cryptomya, Mya) FROM STURGEON AND ROBERTS BANKS (DeMill, personal communication)[1]

Metal	Area	µg/g Dry Weight				µg/g Wet Weight			
		Sample Size	No. of Indiv.	Mean Concen.	S.D.	Sample Size	No. of Indiv.	Mean Concen.	S.D.
Arsenic	A	8	463	8.12	1.67	8	463	1.26	0.28
	B	8	431	8.37	1.48	8	431	1.40	0.25
	C	7	339	7.36	1.29	7	339	1.18	0.26
	D	9	335	30.7*	66.1	9	335	4.93*	10.87
	D^2	8	293	8.64	1.84	8	293	1.31	0.42
Cadmium	A	8	463	3.34	3.08	8	463	0.522	0.513
	B	8	431	10.6	23.5	8	431	1.50	3.14
	C	7	339	31.0*	62.7	7	339	4.10*	7.88
	C^2	6	319	2.35	1.83	7	319	0.397	0.286
	D	9	335	3.24	3.79	9	335	0.524	0.642
Chromium	A	8	463	2.00	0.489	8	463	0.324	0.132
	B	8	431	2.37	0.937	8	431	0.399	0.166
	C	7	339	2.05	0.618	7	339	0.340	0.124
	D	9	335	1.52	0.258	9	335	0.228	0.048
Copper	A	8	463	39.1	30.4	8	463	6.21	4.65
	B	8	431	50.1	41.3	8	431	10.4	8.05
	C	7	339	23.8	11.2	7	339	3.85	1.88
	D	9	335	23.9	8.73	9	335	3.58	1.36
Iron	A	8	463	745	362	8	463	116	51.6
	B	8	431	610	369	8	431	103	61.6
	C	7	339	789	339	7	339	125	47.9
	D	9	335	927	404	9	335	135	43.9
Nickel	A	8	463	3.91	0.71	8	463	0.60	0.09
	B	8	431	5.36	1.38	8	431	0.89	0.23
	C	7	339	5.16	2.09	7	339	0.82	0.28
	D	9	335	5.22	2.14	9	335	0.76	0.20
Lead	A	8	463	4.17	0.27	8	463	0.65	0.13
	B	8	431	5.24	1.09	8	431	0.88	0.19
	C	7	339	4.27	0.62	7	339	0.69	0.14
	D	9	335	4.62	1.24	9	335	0.69	0.19
Zinc	A	8	463	304	91.6	8	463	48.6	17.8
	B	8	431	231	106	8	431	38.9	18.2
	C	7	339	229	73.9	7	339	37.2	12.9
	D	9	335	203	80.2	9	335	31.6	14.7

A - North of Iona Jetty. (Stations 1-8; Figure 22).
B - South of jetty in the zone of influence. (Stations 12-15, 17, 19, 20; Figure 22).
C - South of Sturgeon Bank. (Stations 21-23, 26-28; Figure 22).
D - Roberts Bank. (Stations 29-35; Figure 22).
S.D. - Standard deviation.
* - Dubious data.
1 - Environmental Protection Service, unpublished data.
2 - Means and standard deviation omitting questionable data.

TABLE 3-30

CANADIAN FOOD AND DRUGS ACT REGULATIONS*

Years Regulations Effective	Food Category	Parameter (μg/g Wet Weight)			
		Arsenic	Lead	Copper	Zinc
1975-1978	Marine and Fresh Water Animal Products	5	10	100	100
	Fish Protein	3.5	0.5	-	-
1979-	Fish Protein	3.5	0.5	-	-

* The enforcement level for mercury in fish and shellfish used by the Food and Drug Directorate of 0.5 μg/g wet weight is a guideline level set by the administration not by the regulations.

TABLE 3-31

MERCURY CONCENTRATIONS IN *Macoma balthica* FROM STURGEON AND ROBERTS BANKS (DeMill, personal communication)[1]

(µg/g Wet Wt.)

Station (Refer to Figure 22)	No. of Samples	Mean	Standard Deviation	Rank
1	5	0.040	0.0173	27
2	5	0.102	0.0228	8
3	5	0.172	0.0763	1
4	5	0.064	0.0182	16
5	5	0.038	0.0084	29
6	5	0.074	0.0207	13
7	5	0.074	0.0219	14
8	5	0.088	0.0311	11
9	5	0.042	0.0110	26
10	-	-	-	-
11	-	-	-	-
12	10	0.066	0.0052	15
13	5	0.092	0.0217	10
14	5	0.138	0.0335	2
15	5	0.060	0.0300	17
16	-	-	-	-
17	5	0.054	0.0195	18
18	5	0.050	0.0100	21
19	5	0.046	0.0154	24
20	5	0.138	0.0444	3
21	5	0.044	0.0152	25
22	5	0.120	0.0412	6
23	5	0.038	0.0179	30
24	5	0.050	0.0100	22
25	6	0.132	0.0685	4
26	5	0.054	0.0182	19
27	5	0.054	0.0207	20
28	5	0.040	0.0158	26
29	6	0.050	0.0167	23
30	5	0.110	0.1057	7
31	5	0.036	0.0089	31
32	5	0.100	0.0300	9
33	5	0.118	0.0383	5
34	5	0.080	0.0100	12
35	11	0.027	0.0090	32

Stations ranked according to Newman-Keuls method (Zar, 1974).

3/14;20/25/22/33/30/2/32/13/8/34/6;7/12/4/15/17;26;27/18;24;29/19/21/9/1;28/5;23/31/35

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[1] Environmental Protection Service, unpublished data.

TABLE 3-32

CONCENTRATION OF HEAVY METALS IN TISSUES OF *Macoma balthica* NEAR THE IONA ISLAND STP OUTFALL AND FROM ROBERTS BANK

Parameter and Reference for Data	Cadmium (µg/g dry wt.)				Copper (µg/g dry wt.)				Iron (µg/g dry wt.)				Lead (µg/g dry wt.)			
Collection Sites (Refer to Figure 10)	*	**	***	****	*	**	***	****	*	**	***	****	*	**	***	****
Sturgeon Bank	n=1	n=1	n=1	n=6	n=1	n=1	n=1	n=6	n=1	n=1	n=1	n=6	n=1	n=1	n=1	n=6
b2	1.77	-	-	0.44	44.0	-	-	146	737	-	-	-	<4.42	-	-	-
b5	-	-	N.D.	-	-	-	314	-	-	-	476	-	-	-	N.D.	-
B2	-	-	N.D.	-	-	-	171	-	-	-	1452	-	-	-	N.D.	-
C	2.5	-	-	-	137	124	-	-	727	17 400	-	-	6.26	20.6	-	-
C5	-	-	N.D.	-	-	-	74.6	-	-	-	700	-	-	-	N.D.	-
d	-	-	-	-	-	103	-	-	-	14 200	-	-	-	32.0	-	-
D	<0.95	-	-	-	88.2	102	-	-	1000	18 500	-	-	6.35	25.3	-	-
D5	1.33	-	N.D.	-	29.5	-	49.1	-	689	-	369	-	<4.28	-	N.D.	-
D8	6.35	-	N.D.	-	39.7	-	51.4	-	1120	-	797	-	<6.28	-	N.D.	-
e2	1.61	-	-	N.D.	20.2	-	-	57.8	158	-	-	-	< 3.9	-	-	-
Roberts Bank North of the Westshore Terminals	n=2			n=6	n=2			n=6	n=2				n=2			
	2.96	-	-	<1.84	26.6	-	-	44.0	1246	-	-	-	<4.68	-	-	-

* DeMill, Environmental Protection Service, unpublished data.
** Bindra and Hall, 1977.
*** McGreer, 1979a.
**** McGreer and Vigers, 1979.
- No data.
N.D. Not detectable.
n Sample size; these are pooled samples usually containing more than 20 individuals.

TABLE 3-32 (CONTINUED)

CONCENTRATION OF HEAVY METALS IN TISSUES OF *Macoma balthica* NEAR THE IONA ISLAND STP OUTFALL AND FROM ROBERTS BANK

Parameter and Reference for Data	Zinc (µg/g dry wt.)				Arsenic (µg/g wet wt.)				Mercury (µg/g wet wt.)			
Collection Sites (Refer to Figure 10)	*	**	***	****	*	**	***	****	*	**	***	****
Sturgeon Bank	n=1	n=1	n=1	n=6	n=1	n=1	n=1	n=6	n=5 or 10	n=1	n=1	n=6
b2	220	-	-	299	<7.4	-	-	<1.06	0.05	-	-	0.16
b5	-	-	743	-	-	-	-	-	-	-	0.60	-
B2	-	-	392	-	-	-	-	-	-	-	0.22	-
C	243	229	-	-	<7.2	-	-	-	0.07	-	-	-
C5	-	-	532	-	-	-	-	-	-	-	0.07	-
d	-	220	-	-	-	-	-	-	-	-	-	-
D	283	248	-	-	<9.5	-	-	-	0.09	-	-	-
D5	303	-	399	-	<7.1	-	-	-	0.05	-	0.07	-
D8	422	-	406	-	<11	-	-	-	0.14	-	0.08	-
e2	95	-	-	352	<6.9	-	-	<1.12	0.14	-	-	0.10
Roberts Bank North of the Westshore Terminals	n=2			n=6	n=2			n=6	n=15			n=6
	298			303	<1.3			<1.5	0.03			0.06

* DeMill, Environmental Protection Service, unpublished data.
** Bindra and Hall, 1977.
*** McGreer, 1979a.
**** McGreer and Vigers, 1979.
\- No data.
N.D. Not detectable.
n Sample size; these are pooled samples usually containing more than 20 individuals.

TABLE 3-33

CONCENTRATIONS OF TRACE METALS IN Cancer magister FROM THE BANKS (μg/g Dry Wt.)

Location (See Figure 25)	Arsenic* Mean Range	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Silver Mean Range	Zinc Mean Range	Mercury* Mean Range
Roberts Bank[1] North of Tsawwassen Terminal; n=5	- -	<1.1 <1.0- <1.3	<6.4 <6.0- <8.0	63 51-68	<2.0 -	1.7 1.3-3.4	<5.4 <5.0- <7.0	<1.5 <1.4- <2.0	190 170-210	0.08 0.04-0.18
Roberts Bank[2] North of the Westshore Terminal; n=20	5.2 1.3-12	N.D. -	- -	57 33-112	- -	- -	- -	- -	271 221-379	0.17 0.03-0.37
Roberts Bank[3] n=2	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.06 0.06-0.07
Sturgeon Bank[1] North of the Iona Island Jetty; n=12	- -	<1.4 <1.3-3.1	<8.0 -	77 38-150	<2.0 -	6.5 3.8-21	<7.1 <7.0- <8.0	<1.6 <1.3-4.3	225 140-290	0.34 0.07-0.70
Sturgeon Bank[2] South of the Iona Island Jetty; n=20	6.7 2.2-20	N.C. N.D.-0.64	- -	50 31-84	- -	- -	- -	- -	281 210-429	0.25 0.14-0.37
Sturgeon Bank[3] at Iona Island and South; n=7	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.24 0.11-0.42

[1] Bawden et al., 1973.
[2] McGreer and Vigers, 1979.
[3] Harbo and Birtwell, 1977.
- No data.
N.D. Not detectable.
N.C. Not calculated.
n Number of samples.
* μg/g wet wt.

TABLE 3-34

CONCENTRATIONS OF TRACE METALS IN CRUSTACEANS FROM VARIOUS LOCATIONS

($\mu g/g$ Unit Wt.)

Species and Sample Location	No. of Samples	Arsenic Mean Range (wet wt.)	Cadmium Mean Range (dry wt.)	Cobalt Mean Range (dry wt.)	Copper Mean Range (dry wt.)	Lead Mean Range (dry wt.)	Manganese Mean Range (dry wt.)	Nickel Mean Range (dry wt.)	Silver Mean Range (dry wt.)	Zinc Mean Range (dry wt.)	Mercury Mean Range (wet wt.)
Cancer magister											
Kitimat Arm[1]	6	- -	< 1.0 -	< 8.0 -	32 22-42	< 2.0 -	1.9 1.4-2.4	< 8.0 -	0.2 0.1-0.3	206 180-250	0.07* 0.03-0.10*
Cowichan Bay[1]	5	- -	< 1.0 -	< 6.0 -	43 18-57	< 2.0 -	1.4 0.9-1.7	< 5.0 -	< 1.4 -	186 170-210	0.03 0.02-0.09
N.W. Coast[2] Vancouver Is.	54	(7.0) 2.2-38	- -	- -	- -	- -	- -	- -	- -	- -	- -
Inlet System, N.W.[3] Tip Vancouver Is.	12	6.7 4.7-8.4	0.46* 0.05-1.35*	- -	59* 30-86*	0.6* 0.5-1.0*	- -	- -	- -	198* 124-232*	0.08 0.03-0.15
Port Hardy,[4] Hardy Bay	11	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.12 0.04-0.25
Pender Harbour,[4] Malaspina Strait	4	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.11 0.07-0.13
Howe Sound (1975)[5]	52	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.14 0.05-0.88

[1] Bawden et al., 1973.
[2] LeBlanc and Jackson, 1973.
[3] Utah Mines Ltd., 1978.
[4] Harbo and Birtwell, 1977.
[5] Harbo and Birtwell, 1978.
* Estimated figures, assuming 80% moisture as suggested in [1].
- No data.
( ) Median value only reported.

TABLE 3-34 (CONTINUED)

CONCENTRATIONS OF TRACE METALS IN CRUSTACEANS FROM VARIOUS LOCATIONS

(µg/g Unit Wt.)

Species and Sample Location	No. of Samples	Arsenic Mean Range (wet wt.)	Cadmium Mean Range (dry wt.)	Cobalt Mean Range (dry wt.)	Copper Mean Range (dry wt.)	Lead Mean Range (dry wt.)	Manganese Mean Range (dry wt.)	Nickel Mean Range (dry wt.)	Silver Mean Range (dry wt.)	Zinc Mean Range (dry wt.)	Mercury Mean Range (wet wt.)
Cancer anthonyi											
Palos Verdes Shelf, California, Site of Los Angeles County Outfall[6]	?	- -	(< 0.05*) -	- -	(39.5*) -	(0.7*) -	- -	(1.3*) -	(0.5*) -	(100*) -	(0.03) -
North Santa Monica Bay, California[6]	?	- -	(0.05*) -	- -	(65.0*) -	(0.8*) -	- -	(0.2*) -	(1.1*) -	(485*) -	(0.07) -
Pandalus borealis											
Mamorilik, Greenland[7]	3	14.0* 12.6-16.0*	- -	- -	- -	- -	- -	- -	- -	- -	- -
Crabs spp.											
Thames Estuary[8]	?	35.0 -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Prawns spp.											
Thames Estuary[8]	?	55.0 -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Shrimp spp											
Thames Estuary[8]	?	18.0 -	- -	- -	- -	- -	- -	- -	- -	- -	- -
U.S. Commercial Data[8]	?	1.5 -	- -	- -	- -	- -	- -	- -	- -	- -	- -

[6] California Coastal Study, 1977.
[7] Bohn, 1975.
[8] Penrose, 1974.
* Estimated figures, assuming 80% moisture as suggested in [1].
- No data.
( ) Median value only reported.

TABLE 3-35

SUMMARY OF TRACE METAL DATA FROM EPAXIAL MUSCLE TISSUE OF LOWER FRASER RIVER FISH (µg/g Wet Wt.) (DRINNAN AND NORTHCOTE, IN PREPARATION)

Species	No. of Samples	Length (mm) Mean ± 1 S.D. (Range)	Copper Mean ± 1 S.D. (Range)	Copper Median	Mercury Mean ± 1 S.D. (Range)	Mercury Median	Zinc Mean ± 1 S.D. (Range)	Zinc Median
White Sturgeon (Acipenser transmontanus)	51	439±93.7 (248-718)	0.44±0.22 (0.12-0.97)	0.40	0.30±0.28 (0.05-1.28)	0.18	4.28±1.61 (2.23-8.60)	4.01
Mountain Whitefish (Prosopium williamsoni)	9	262±31.1 (192-297)	0.61±0.18 (0.38-0.85)	0.58	0.10±0.10 (0.03-0.29)	0.06	4.79±1.13 (3.41-7.20)	4.46
Dolly Varden (Salvelinus malma)	28	341±99.6 (262-428)	0.51±0.19 (0.19-0.95)	0.49	0.12±0.04 (0.05-0.23)	0.11	5.28±1.59 (3.45-10.10)	4.66
Cutthroat Trout (Salmo gairdneri)	29	316±77.0 (165-565)	0.59±0.21 (0.30-1.21)	0.50	0.09±0.03 (0.05-0.17)	0.09	4.63±1.58 (3.33-11.50)	4.31
Rainbow Trout (S. clarki)	45	304±51.0 (231-442)	0.63±0.19 (0.22-1.00)	0.65	0.09±0.05 (0.02-0.31)	0.08	4.93±1.43 (3.20-9.21)	4.73
Bridgelip Sucker (Catostomus columbianus)	3	246±23.9 (219-263)	0.71±0.16 (0.57-0.88)	0.69	0.05 (0.05)	0.05	10.55±7.68 (5.54-19.40)	6.72
Largescale Sucker (C. macrocheilus)	116	367±62.6 (204-537)	0.46±0.18 (0.10-1.00)	0.44	0.32±0.19 (0.05-0.82)	0.28	6.17±2.03 (3.12-15.02)	5.80
Carp (Cyprinus carpio)	4	480±57.3 (436-557)	0.41±0.14 (0.26-0.60)	0.39	0.32±0.08 (0.22-0.41)	0.33	5.86±3.03 (3.10-10.13)	5.11
Peamouth Chub (Mylocheilus caurinus)	125	229±31.9 (10.4-288)	0.75±0.36 (0.17-2.42)	0.68	0.31±0.17 (0.08-1.01)	0.26	9.68±4.26 (3.81-29.25)	8.66
Northern Squawfish (Ptychocheilus oregonensis)	90	314±61.3 (153-460)	0.60±0.24 (0.12-1.70)	0.60	0.68±0.38 (0.06-1.99)	0.59	6.49±2.20 (3.27-16.07)	6.09
Redside Shiner (Richardsonius balteatus)	1	131 -	0.71 -	-	0.09 -	-	21.07 -	-
Black Crappie (Pomoxis nigromaculatus)	5	191±14.4 (173-213)	0.35±0.04 (0.30-0.39)	0.36	0.21±0.06 (0.13-0.29)	0.21	6.08±0.85 (5.16-7.15)	6.10
Burbot (Lota lota)	1	430 -	0.16 -	-	0.18 -	-	5.20 -	-
Prickly Sculpin (Cottus asper)	31	167±33.5 (111-268)	0.53±0.12 (0.27-0.74)	0.54	0.67±0.50 (0.07-2.19)	0.54	11.91±3.19 (5.90-21.01)	11.63

S.D. - Standard deviation.

TABLE 3-36

CONCENTRATION OF METALS IN AMMOCOETE LARVAE FROM THE FRASER RIVER

(µg/g Dry Wt.)

Site	Cadmium Mean Range	Cobalt Mean Range	Copper Mean Range	Iron Mean Range	Lead Mean Range	Manganese Mean Range	Nickel Mean Range	Zinc Mean Range	Mercury (n=2) Mean Range
North of Western[1] Tip Barnston Island; n=3	<1.0* -	- -	24.7 19.0-30.0 (0.9)	1 155 745-1510 (0.1)	15.7 3.0-40.0 (1.3)	28.3 16.0-36.0 (0.1)	<6.7 <6.0- <7.0*	116 109-130 (2.1)	1.36 1.11-1.62 (19.4)
Downstream Poplar[1] Island; n=1	- -	- -	- -	- -	- -	- -	- -	- -	1.16 - (14.2)
Downstream Annacis[1] Island; n=1	<1.0* -	- -	25.0 - (0.9)	4 526 - (0.2)	8.0 - (0.7)	94.0 - (0.2)	9.5 - (0.2)	125 - (1.8)	0.83 - (10.4)
New Westminster[2]; n=6	7.5 <0.5-37 (3.4)	3.0 <0.5- <4.0*	10.5 5.1-14 (0.3)	1 150 578-2240 (0.1)	21.0 2.0-88.0 (0.2)	27.5 13.4-56.0 (0.1)	<5.5 <2.0- <6.0*	147 46.8-600 (0.7)	1.20; n=3 0.59-1.80 (12.0)
Oak Street[2]; n=2	<1.5 <1.0- <2.0*	2.4 1.9-2.8 (0.2)	10.4 8.4-12.3 (0.3)	1 080 333-1 830 (0.1)	4.4 1.9-7.0 (0.1)	17.3 6.8-27.8 (0.1)	<2.5 <2.0- <3.0*	101 98.4-104 (0.9)	- -

[1] W.L.B., unpublished data.

[2] Chapman et al., in preparation; conversions from µg/g tissue dry weight to µg/g sample dry weight and data calculations by author.

( ) Bioconcentration Factor $= \frac{\text{Concentration of metal in organism}}{\text{Concentration of metal in sediment (Table 3-12)}}$

* Bioconcentration Factor not calculated due to proximity of some values to detection limits in biota or sediments.

- No data.

n Number of samples.

TABLE 3-37

LEVELS OF METALS IN FISH MUSCLE TAKEN FROM WATERSHEDS OF BRITISH COLUMBIA
(μg/g DRY WEIGHT EXCEPT MERCURY GIVEN AS WET WEIGHT)

Fish Species	Location	No. of Samples	Copper Mean Range	No. of Samples	Mercury Mean Range	No. of Samples	Zinc Mean Range	References
Rainbow Trout (Salmo gairdneri)	Great Central Lake	7	1.6 1.1-2.5	7	0.10 0.06-0.15	7	17.5 13.5-24.5	Baillie and Morrison, 1977
	Buttle Lake	26	2.8 1.4-6.6	26	< 0.07 <0.05-0.12	26	18.3 12.5-35.4	Baillie and Morrison, 1977
	Lower Arrow Lakes	3	2.3 2.0-2.5	3	0.11 0.06-0.14	10	24.0 19.2-26.0	Gregory, 1979
	Columbia R., D/S Smelter at Trail	1	1.8	1	< 0.05	4	17.3 12.8-20.7	Gregory, 1979
Cutthroat Trout (S. clarki)	Alice Lake	6	2.2 1.9-2.8	-	- -	6	26.0 17.2-33.2	Baillie and Morrison, 1977
	Benson Lake	3	2.4 0.6-2.5	3	0.13 0.05-0.24	3	19.0 17.7-21.5	Baillie and Morrison, 1977
	Maynard Lake	-	- -	-	- -	10	20.7 16.5-25.9	Baillie and Morrison, 1977
Trout, spp.	Bear Creek	3	2.4 1.8-2.7	-	- -	3	72.0 55.0-90.0	Kelso, unpublished data
Dolly Varden (Salvelinus malma)	Alice Lake	10	2.3 1.3-3.6	5	0.20 0.14-0.23	10	22.0 14.5-33.8	Baillie and Morrison, 1977
	Benson Lake	19	3.0 0.5-5.6	19	0.20 0.05-0.35	19	20.6 14.9-34.0	Baillie and Morrison, 1977
	Columbia R., D/S Hugh Keenleyside Dam	1	2.0 -	1	0.26 -	1	18.0 -	Clark, unpublished data
Carp (Cyprinus carpio)	Columbia R., D/S Hugh Keenleyside Dam	2	3.5 3.0-4.0	2	0.06 0.05-0.08	2	62.5 50.0-75.0	Clark, unpublished data
Burbot (Lota lota)	Columbia R., D/S Hugh Keenleyside Dam	1	2.0 -	1	0.30 -	1	42.0 -	Clark, unpublished data

D/S Downstream
- No data

TABLE 3-37 (CONTINUED)

LEVELS OF METALS IN FISH MUSCLE TAKEN FROM WATERSHEDS OF BRITISH COLUMBIA

(µg/g DRY WEIGHT EXCEPT MERCURY GIVEN AS WET WEIGHT)

Fish Species	Location	No. of Samples	Copper Mean Range	No. of Samples	Mercury Mean Range	No. of Samples	Zinc Mean Range	References
Mountain Whitefish (Prosopium williamsoni)	Lower Arrow Lakes	3	1.9 1.5–2.3	4	0.07 0.06–0.08	10	15.9 12.7–20.8	Gregory, 1979
	Columbia R., D/S Smelter at Trail	3	1.7 1.5–1.9	9	0.07 0.05–0.10	9	15.7 12.0–26.0	Gregory, 1979
	Columbia R., D/S Hugh Keenleyside Dam	26	1.9 1.0–3.0	26	0.10 < 0.05–0.57	26	16.1 12.0–19.0	Clark, unpublished data
Largescale Sucker (Catostomus macrocheilus)	Lower Arrow Lakes	3	2.0 1.8–2.2	3	0.22 0.18–0.24	10	26.0 20.5–32.3	Gregory, 1979
	Columbia R., D/S Smelter at Trail	3	3.0 2.7–3.4	10	0.11 0.05–0.20	10	35.1 26.3–47.3	Gregory, 1979
	Columbia R., D/S Hugh Keenleyside Dam	4	2.2 2.0–3.0	4	0.11 0.07–0.20	4	37.0 34.0–42.0	Clark, unpublished data
	Fraser Canyon	2	3.0 3.0–3.0	2	0.46 0.13–0.80	2	48.0 35.0–61.0	Clark, unpublished data
Peamouth Chub (Mylocheilus caurinus)	Kennedy Lake	32	2.0 0.5–4.0	28	0.19 0.08–0.42	32	102 20.0–150	Baillie and Morrison, 1977
	Lower Arrow Lakes	3	2.1 2.1–2.2	3	0.15 0.13–0.19	10	41.4 31.3–48.2	Gregory, 1979
	Columbia R., D/S Smelter at Trail	3	2.5 2.2–2.6	5	0.15 0.10–0.23	10	31.5 24.1–48.6	Gregory, 1979
	Serpentine R., U/S Portion	1	2.7 -	-	- -	1	95.0 -	Kelso, unpublished data
	Serpentine R., D/S Portion	1	2.8 -	-	- -	1	55.0 -	Kelso, unpublished data
Northern Squawfish (Ptychocheilus oregonensis)	Fraser R., near bridge R.	1	3.0 -	1	0.26 -	1	23.0 -	Clark, unpublished data
	Columbia R., D/S Hugh Keenleyside Dam	6	2.3 1.0–3.0	6	0.34 0.24–0.48	6	30.0 20.0–38.0	Clark, unpublished data

D/S Downstream
U/S Upstream
- No data

TABLE 3-38

METAL CONCENTRATIONS IN EPAXIAL MUSCLE OF COMMERCIAL AND SPORTS FISH SPECIES FROM THE LOWER FRASER RIVER AND BANKS (µg/g Wet Wt.)

Species	No. of Samples	Mercury Mean ± S.D. Range	Arsenic Mean ± S.D. Range	Cadmium Mean ± S.D. Range	Copper Mean ± S.D. Range	Zinc Mean ± S.D. Range
Chinook salmon (Oncorhynchus tshawytscha), from Canoe Pass[1]	2	0.025±0.160 0.020-0.030	- -	- -	0.55±0.21 0.40-0.70	3.2±0.07 3.1-3.2
Sockeye salmon (Oncorhynchus nerka), from Canoe Pass[1]	5	0.040±0.007 0.030-0.050	- -	- -	0.73±0.05 0.69-0.80	4.2±0.56 3.8-5.2
Chinook salmon, juveniles from Sturgeon Bank, south and about 4 km west from the Iona outfall[2]	10	0.094±0.026 0.060-0.130	N.D. -	N.C. N.D.-1.48	0.61±0.09 0.44-0.75	8.0±1.3 6.0-9.9
Chinook salmon, juveniles from Roberts Bank[2]	3	0.077±0.023 0.050-0.090	N.D. -	N.D. -	0.50±0.07 0.46-0.58	8.8±0.85 7.8-9.3
Starry flounder (Platichthys stallatus) juveniles from Sturgeon Bank, south and about 1.5 km west from the Iona outfall[2]	20	0.079±0.030 0.040-0.160	N.D. -	N.D. -	0.63±0.54 0.24-2.2	8.2±1.7 6.1-12
Starry flounder from near Iona Is. and south on Sturgeon Bank[3]	2	0.15+0 -	- -	- -	- -	- -
Starry flounder, juveniles from Sturgeon Bank, south and about 4 km west from the Iona outfall[2]	20	0.164±0.010 0.070-0.440	N.C. N.D.-3.57	N.D. -	0.78±0.36 0.34-1.7	8.5±2.9 5.0-17
Starry flounder, juveniles from Roberts Bank[2]	20	0.068±0.024 0.020-0.370	N.C. N.D.-1.75	N.D. -	0.82±0.66 0.25-3.3	9.0±2.1 6.1-15
Flounder (juvenile) from Roberts Bank[3]	1	0.110 -	- -	- -	- -	- -

1 Northcote, Johnston and Tsumura, 1975.
2 McGreer and Vigers, 1979.
3 Harbo and Birtwell, 1977.
- No data..
N.D. Not detectable.
N.C. No calculated.
S.D. Standard deviation.

TABLE 3-39

METAL CONCENTRATIONS IN MUSCLE TISSUE OF MARINE FISH FROM VARIOUS LOCATIONS

(μg/g Wet Wt.)

Species	Location	Mercury Mean Range	Arsenic Mean Range	Cadmium Mean Range	Copper Mean Range	Zinc Mean Range
Starry flounder (Platichthys stellatus)	Point Grey, Burrard[1] Inlet, B.C.	0.10 (n=1) -	- -	- -	- -	- -
Juvenile flounders	Point Grey, Burrard[1] Inlet, B.C.	0.13 (n=?) 0.09-0.16	- -	- -	- -	- -
Flounder	Pender Harbour, Malaspina[1] Strait, B.C.	0.11 (n=1) -	- -	- -	- -	- -
	Howe Sound, B.C.[2]	0.18 (n=1) -	- -	- -	- -	- -
Winter flounder (Pseudopleuronectes americanus)	New York Bight and[3] Long Island Sound	0.08 (n=2) 0.06-0.09	- -	< 0.10 (n=4) -	0.8 (n=3) 0.5-1.1	5.6 (n=3) 5.2-6.0
	Coast of Maritime[4] Provinces	0.17 (n=10) 0.11-0.20	- -	- -	- -	- -
Yellowtail flounder (Limanda terruginea)	New York Bight and[3] Long Island Sound	0.10 (n=8) 0.06-0.13	- -	0.09 (n=9) 0.05-0.10	0.6 (n=7) 0.3-1.2	4.2 (n=1) -
Flounder (Platichthys flesus)	Lower Medway[5] Estuary, England	0.34 (n=20) 0.04-1.15	- -	0.06 (n=9) 0.06-0.08	0.7 (n=9) 0.3-1.3	15.6 (n=10) 8.0-19.5
Plaice (Pleuronectes platissa)	Lower Medway[5] Estuary, England	0.20 (n=7) 0.15-0.32	- -	0.11 (n=14) 0.05-0.15	0.9 (n=14) 0.5-1.7	11.2 (n=9) 8.3-14.5

[1] Harbo and Birtwell, 1977.
[2] Harbo and Birtwell, 1978.
[3] Greig and Wenzloff, 1977.
[4] Freeman et al., 1974.
[5] Wharfe and van der Broek, 1977.
- No data.
n Number of samples.

TABLE 3-39 (CONTINUED)

METAL CONCENTRATIONS IN MUSCLE TISSUE OF MARINE FISH FROM VARIOUS LOCATIONS

(µg/g Wet Wt.)

Species	Location	Mercury Mean Range	Arsenic Mean Range	Cadmium Mean Range	Copper Mean Range	Zinc Mean Range
Sole (Psettichthys melanostictus and Parophyrus vetalus)	Northwest Coast[6] Vancouver Island	- -	1.1 (n=3) 0.6-12	- -	- -	- -
Atlantic salmon (Salmo par)	Coast of Maritime[3] Provinces	0.11 (n=10) 0.7-0.14	- -	- -	- -	- -
Trout (steelhead) (Salmo gairdneri)	Northwest Coast[6] Vancouver Island	- -	<0.4 (n=1) -	- -	- -	- -
Salmon (Oncorhynchus sp.)	Northwest Coast[6] Vancouver Island	- -	N.D. (n=5) N.D.- <0.4	- -	- -	- -
Coho salmon (Oncorhynchus kisutch)	Cowichan Bay, B.C.[1] (adults)	0.05 (n=6) 0.02-0.10	- -	- -	- -	- -
	Cowichan Bay, B.C.[1] (juveniles)	0.02 (n=5) -	- -	- -	- -	- -
Chum salmon (O. keta)	Pender Harbour, Malaspina Strait, B.C. (adults)	0.04 (n=6) 0.03-0.06	- -	- -	- -	- -

[1] Harbo and Birtwell, 1977.
[3] Greig and Wenzloff, 1977.
[6] LeBlanc and Jackson, 1973.
- No data.
N.D. Not Detectable.
n Number of samples.

TABLE 4-1

ROUTINE MONITORING PROGRAM - BIOTA AND SEDIMENTS

Sample Content	Frequency Year	Sites (Figure 29)	Parameters	Comments
Periphyton	2 (Spring, Late Summer)	1, 2, 3, 4, 6, 7, 8	Arsenic, Mercury, Range of Metals	Techniques are currently being refined to eliminate suspended sediments as a source of contamination.
Invertebrates Immature Chironomids	2 (Late Winter, Late Summer)	Limited by Distribution, Suggest: 1, 4, 8	Arsenic, Mercury, Range of Metals	Systematics of chironomids in lower Fraser must be worked out. Use of drift nets for sample collection should be investigated.
Tubificids	2 (Late Winter, Late Summer)	Limited by Distribution, Suggest: 1, 4, 7, 8	"	Decision on whether or not to account for sediments in gut content: e.g., allow specimens to depurate or correct results by weight. All samples should be treated similarly.
Amphipods	2 (Late Winter, Late Summer)	Limited by Upstream Range, Suggest: 3, 6, 8	"	Use similar method as above to correct for sediments in gut.
Bivalves	2 (Early Summer, Late Fall)	9-17	"	Recommend Crassostrea gigas and Macoma balthica as monitor species due to historical data. Allow specimens to depurate.
Crabs	2 (Early Summer, Late Fall)	9-17	Arsenic, Mercury, Range of Metals	Monitor Cancer magister, muscle tissue.
Fish	River: 1 (Summer) Banks: 2 (Early Summer, Late Fall) Choose Times to Best Collect Various Species	1-9, 11, 13, 14, 16	Arsenic, Mercury, Range of Metals	There should be overlap with species monitored in 1973 and 1979. Additional effort put into monitoring salmon, including juveniles. Monitor epaxial muscle, but consider analysing other tissue types such as liver and gonads and protein extracts.
Sediments	2 (Late Winter, Late Summer or Early Summer, Late Fall) No. of Replicates to be Determined	Where Benthos are Sampled	" In Addition: % Organic Carbon, Particle Size Distribution	

APPENDIX I

WATER INVESTIGATIONS BRANCH, MINISTRY OF ENVIRONMENT, LOWER FRASER RIVER SAMPLING PROGRAM FOR BENTHIC INVERTEBRATES AND SEDIMENTS (1978, 1979)

Introduction

Some riverine benthic invertebrates are fairly stationary organisms and remain in a given river reach for several months before and after freshet. These organisms can provide environmental information relative to the time that they were present in a particular river reach. Tubificid oligochaetes and chironomid larvae are the dominant macroinvertebrates found consistently in the Fraser River, from Kanaka Creek downstream to the Banks in the fine sediments of backwater areas. Both organisms can live up to several months in the sediments. Sediments are often considered reservoirs or sinks for contaminants, and organisms which occupy them may be monitored to indicate whether they accumulate contaminants from them, subsequently introducing these compounds into the food web.

The Water Investigations Branch (W.I.B.), Ministry of Environment, conducted a program in the lower Fraser River to investigate levels of metals in benthic invertebrates and sediments. This program was developed to complement the one being conducted by the Inland Waters Directorate, Environment Canada. Tubificid oligochaetes and at times chironomid larvae were collected from four sites in the lower Fraser River: near the southwest tip of Barnston Island, referred to as downstream from Barnston Island; downstream from Poplar Island in a back slough; at the southwest tip of Mitchell Island, referred to as downstream from Mitchell Island; and a back slough opposite the southwest tip of Annacis Island, referred to as downstream from Annacis Island. The North Arm site labelled as "downstream from Poplar Island" may have also been identified as "downstream from Tree Island" because Tree Island is actually closer to the site than Poplar Island. This identification was not used because there are at least two "Tree Islands" charted in the study area. Muddy, silty sediments were the most suitable substrates to sample for the collection of tubificids and chironomid larvae in large numbers.

Materials and Methods

Benthic invertebrates were collected in a prefreshet period of late February to early April, 1978 and a postfreshet period of August to October, 1978. Sediments were collected when invertebrates were collected.

The following procedures were followed during the collection and sorting of benthos and sediments.

1) Bottom samples were collected from a boat using a Petersen grab. The contents of the grab were dropped into a clean plastic tray and the outside layer of mud which contacted the sampler was removed with a plastic scoop. The remaining sample was transferred to a clean plastic bucket until the mud was sieved.

2) About 20 to 30 grabs were taken at each site.

3) Mud samples were screened through a 500 μm mesh stainless steel sieve on site using pressurized river water.

4) The sievate, composed mainly of wood and organic debris and benthos, was transferred to small clean plastic buckets which when closed were air tight.

5) Upon arrival at the W.I.B. lab, organisms, mainly tubificids, were sorted by hand from the sievate.

6) Portions of the screened material were placed in acid-washed, white plastic trays. Organisms were picked out using stainless steel jewellers' forceps, with the aid of illuminated magnifying lenses, and transferred to dishes containing glass distilled water.

7) Organisms were placed in a second wash of glass distilled water, after which most of the debris had been removed from them.

8) "Cleaned" organisms were placed in acid-washed plastic containers and frozen prior to transfer to the Environmental Laboratory, Ministry of Environment (B.C.), for analysis. This sorting process was extremely labour intensive, as shown by Table I-C.

9) Sediments were also collected using the Petersen grab. Portions of three grab samples were combined to provide a single sample for analysis per sampling occasion.

10) Sediment samples were stored in acid-washed plastic containers and frozen upon arrival at the W.I.B. lab.

11) All samples were transferred frozen to the Environmental Laboratory where they were analysed for metals as outlined in Tables 3-4 and 3-20 in the text of this report.

12) Particle size analyses of sediment samples were carried out by the Ministry of Transportation and Highways, Geotechnical and Materials Engineering Laboratory, using a hydrometric technique.

Results

The raw data are shown in Tables I-A and I-B and are presented in summary in tables 3-12, 3-21 and 3-25 respectively. These data summaries are discussed in sections 3.3.2.2 and 3.3.3.2 (b) of the text of the report.

APPENDIX I

TABLE I-A

LEVELS OF METALS IN BACKWATER SEDIMENTS OF THE LOWER FRASER RIVER (µg/g Dry Wt.)

Site	Date	Cadmium	Chromium	Copper	Lead	Nickel	Arsenic	Iron	Manganese	Zinc	Mercury
Downstream Barnston Island	78-03-28	3.0	35	27	20	50	4.0	23 300	428	61	0.08
	78-02-22	-	-	-	-	-	-	-	-	-	0.11
	78-04-12	2.0	36	28	20	50	4.0	23 000	418	62	0.10
	78-07-25	< 1.0	-	28	8.0	38	5.0	24 800	527	54	0.07
	78-08-01	< 1.0	-	25	7.0	35	4.0	21 200	442	48	0.05
	78-09-26	< 1.0	-	24	6.0	36	3.0	21 200	441	48	0.06
Downstream Poplar Island	78-02-22	-	-	-	-	-	-	-	-	-	0.11
	78-03-28	2.0	32	28	40	40	3.0	22 000	369	127	0.11
	78-07-26	< 1.0	-	28	29	39	5.0	24 800	473	130	0.06
	78-08-02	< 1.0	-	26	23	36	5.0	23 400	447	128	0.08
	79-09-27	< 1.0	-	34	12	43	7.0	29 800	510	74	0.08
Downstream Mitchell Island	78-02-23	-	-	-	-	-	-	-	-	-	0.14
	78-03-28	3.0	37	29	40	50	3.0	22 500	317	116	0.11
	78-07-26	< 1.0	-	25	32	31	4.0	20 300	339	100	0.06
	78-08-02	< 1.0	-	33	45	39	6.0	26 100	479	136	0.12
Downstream Annacis Island	78-02-23	-	-	-	-	-	-	-	-	-	0.05
	78-04-06	3.0	48	23	20	60	6.0	30 600	578	95	0.15
	78-07-25	< 1.0	-	30	9.0	39	5.0	26 000	583	58	0.06
	78-08-01	< 1.0	-	30	8.0	40	4.0	25 700	560	59	0.07
	78-09-26	< 1.0	-	32	9.0	41	4.0	27 300	525	63	0.09

- No data.

APPENDIX I

TABLE I-B

LEVELS OF METALS IN BENTHIC INVERTEBRATES OF THE LOWER FRASER RIVER (µg/g Dry Wt.)

Site	Date	Tissue	% Moisture	Cadmium	Copper	Lead	Nickel	Arsenic	Chromium	Iron	Manganese	Zinc	Mercury
Downstream Barnston Island	78-03-28	Oligochaetes (80%) and Chironomid Larvae (20%)	74.2	1.0	34.0	10	13	4.0	7.0	6 680	291	130	-
	78-02-22	"	84.3	-	-	-	-	-	-	-	-	-	0.45
	78-09-26	Oligochaetes (90%) and Chironomid Larvae (10%)	88.1	< 1.0	21.0	4.0	10	25	-	3 030	108	127	-
	78-08-01	"	83.6	-	-	-	-	-	-	-	-	-	0.54
Downstream Poplar Island	78-02-22	Oligochaetes (90%) and Chironomid Larvae (10%)	84.0	-	-	-	-	-	-	-	-	-	0.50
	78-08-02	"	85.3	< 1.0	15.0	10	< 7	16	-	3 010	74	152	-
	79-09-27	"	93.2	-	-	-	-	-	-	-	-	-	1.78

- No Data.

APPENDIX I

TABLE I-B (CONTINUED)

LEVELS OF METALS IN BENTHIC INVERTEBRATES OF THE LOWER FRASER RIVER (µg/g Dry Wt.)

Site	Date	Tissue	% Moisture	Cadmium	Copper	Lead	Nickel	Arsenic	Chromium	Iron	Manganese	Zinc	Mercury
Downstream Mitchell Island	78-02-23	Oligochaetes	88.8	-	-	-	-	-	-	-	-	-	1.25
	78-03-28	Oligochaetes (90%) and Chironomid Larvae (10%)	84.7	-	-	-	-	-	-	-	-	-	0.59
			84.9	< 1.0	22.0	12	10	6.0	8.0	5 610	85	150	-
	78-08-02	Oligochaetes (90%) and Chironomid Larvae (10%)	83.0	< 1.0	11.0	8.0	< 5	17	-	2 680	52	82	-
			83.4	-	-	-	-	-	-	-	-	-	0.59
Downstream Annacis Island	78-02-23	Oligochaetes (90%) and Chironomid Larvae (10%)	89.9	< 1.0	34.0	12	14	11	8.0	8 120	171	143	-
	78-04-06	Oligochaetes	88.2	-	-	-	-	-	-	-	-	-	0.99
	78-07-25	Oligochaetes (90%) and Chironomid Larvae (10%)	86.7	< 1.0	21.0	3.0	7.0	32	-	2 870	81	160	
	78-09-26	"	85.8	-	-	-	-	-	-	-	-	-	0.64

- No Data.

APPENDIX I

TABLE I-C

Sample*	Dates of Collection	Field		Laboratory	
		Number of Man Days**	Number of Petersen Grabs Taken	Number of Man Days**	Estimated Biomass of Sample (Wet Weight)
D/S Barnston Is.	78-09-26	3	30	4	4.0 g
D/S Annacis Is.	78-07-25	3	19	3	5.4 g
D/S Poplar Is.	78-08-02	1.5	22	2.5	13.7 g
D/S Mitchell Is.	78-08-02	1.5	22	2.5	9.2 g

* These samples were analysed for a range of metals. A duplicate effort was usually necessary to provide enough sample for mercury analysis.

** 1 Man Day = 7 Hours.

D/S Downstream.